THE USE OF STEEL

FOR CONSTRUCTIVE PURPOSES;

METHOD OF WORKING, APPLYING AND TESTING PLATES AND BARS;

BY

J. BARBA,

CHIEF NAVAL CONSTRUCTOR AT L'ORIENT.

(*Translated from the French*)

WITH A PREFACE

BY ALEX. L. HOLLEY, C.E.

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PREFACE.

THERE are two groups of facts regarding the modern steel business, which especially concern the American manufacturers and users of this material.

1st. Three French men-of-war, built out of Bessemer and Martin steels, were so successfully constructed in 1873 that three more large ships were ordered in 1874, to be built from the same materials. Several Bessemer works in England are running exclusively on a general merchant product having a large range of grades and uses, and taking the place of both crucible steel and wrought iron. The Continental works are turning probably a third of their Bessemer product and nearly all their Martin product into other forms than rails. All the late locomotives—many hundreds—on the London and North Western Railway are built of Bessemer steel, excepting only the wheels and necessary castings. Everywhere, abroad, Bessemer and Martin steels are more and more extensively and satisfactorily employed for ship and boiler plates, beams, channels and angles for ships, bridges and other structures, railway tires and axles, general shafting, agricultural implements and the multi-

tudinous forms of machinery bars, and forgings. In the railway and machine shops, the bridge works and shipyards of Europe and of France especially, the method of treating steel—of heating and shaping it and building it successfully into machinery and engineering structures, has become, what it must everywhere become, before this material can be employed to the best advantage, a distinct and highly developed art.

2d. In the United States, out of a Bessemer product of 350,000 tons per year, probably less than 6000 tons are used for other purposes than rails. Very few Bessemer works have any machinery for producing the various constructive shapes required, or any experience in making steel of high or low grades. Bessemer manufacturers are talking about reducing product, in the fear that rail orders will fall below the capacity of their works. Martin steel is now made in American works, regularly and successfully, of all grades, from springs down to boiler-plates, thus furnishing every constructive grade required. Engineers and machinists are generally asking for just such material as steel has proved to be abroad, but are yet hesitating about the use of steel, because our Bessemer manufacturers have not got much into the way of making other grades than rail steel, and Martin manufacturers have not until quite recently begun to adopt those improvements in plant and practice which will make steel cheaply; and also because our artisans have not in most cases made any study of the art of working steel, and are therefore afraid of it. Experts say that the use of wood, not only in ocean vessels, but in river and lake boats and barges, must soon give way to the use of metal, as it has done abroad and is beginning to do here; and there are thousands of wooden bridges on our railways

and highways which must soon be replaced by metal; so that for these two large uses, not to speak of general machine construction, there is growing up a vast market for a better material than iron. Excellent pig for the production of cheap steel is obtainable in all parts of the country, and ferro-manganese, upon which important qualities of constructive steels depend, is now cheap enough to warrant its general use.

In short, with every facility for making the products so largely needed here, and so largely used abroad—with the best steel works in the world, and working organizations in them which have increased product and decreased cost in a remarkable degree, we are devoting more concentrated action to schemes for preventing over production than we are to adapting grades and shapes of product to the various constructive uses, and to teaching artisans how to heat, shape and apply them.

In view of this state of affairs, it seems to me that the dissemination among our steel makers and users, of the facts contained in M. Barba's little book, should be of great advantage, 1st, to our engineers and machinists, by making more conspicuous the nature of steel and of the new and important art of working steel: 2d, to the managers and owners of large enterprises in construction and transportation, by revealing to them the fact that steel is such a tractable and valuable material; and 3d, to our steel makers, by showing them that a vast want exists for products which they *can* make, and what kind of steel and treatment of steel will enable them to take advantage of this existing want.

It is to be regretted that M. Barba did not give us the analyses of the steels employed—not even their percentages of carbon. This addition would have made his

work complete. But by comparing the tensile resistances and elongations of the steels he mentions, with those of other steels from the same works and with Belgian steels, of which I have analyses and mechanical tests, I judge the materials put into these French ships to have had between 0.25 and 0.33 per cent. of carbon. These or even lower steels can be readily and uniformly produced in our Bessemer works, while Martin steel can be made as low as 0.10 carbon without difficulty.

It is very interesting and important to note that steels which harden and temper as readily as these do, and which hence so readily acquire dangerous internal strains, can be made so completely tractable and can be so insured against fracture in manufacture and use, by proper manipulation and by heating at the right times—additions to the ordinary iron-working processes, which are not so very costly when works are once fitted out with suitable apparatus.

Another important fact demonstrated at the Barrow works in England (set forth by Mr. Josiah T. Smith in a late paper before the Inst. of Civil Engineers), and most completely proved by these French experiments, is that the injury done to steels of rail grade and below, by cold punching, is confined to the skin of the hole ($\frac{4}{100}$ inch thick in this case); and that this injury is only hardening by pressure which may be completely removed by tempering or annealing, or by reaming out this thin ring of hardened metal. The manner in which this was proved, is a commentary on the nicety of French experimenting.

It has not probably occurred to many boiler-makers who could do nothing with these grades of steel, and so have condemned steel altogether, that shearing and

locally hammering plates puts them in a condition similar to that produced by cold punching, which reduces the strength of the parts most affected, above 20 per cent. Nor has it perhaps occurred to engineers who believe in steel and are anxious to give it a fair chance, to dispense with that class of smiths and boiler makers who cannot be told anything about the treatment of steel, and will not yield to any new requirements—just as these French engineers turned out the skilled workmen who could not treat plates and bars without cracking them, and substituted carpenters, who being willing to follow instructions, made a success from the start.

The adaptability of steel to constructive purposes is specially shown in stamped work, such as pieces shaped like a low-crowned hat, of which 700 were produced without losing one, while not one good piece could be stamped out of iron. The facts that steel crystallizes less than iron by heating without working, and that steel plates have practically the same strength with, and across the "grain," are greatly in its favor.

The hardening of beams and angles of comparatively uniform section, in the last passes of the rolls, is demonstrated, and this should be a rebuke to those engineers who insist that a rail is as unlikely to break when it has a very thin flange which must come out of the rolls at a dark red heat, as if it had a thicker flange which would finish hotter.

The manner in which carbon exists in steel—in solution and in mechanical mixture—also the hardening effects of suddenly cooling steel and of cold hammering, shearing and punching, viz., hardening due to pressure; also the solution and dissemination of carbon by heat, are fully treated in this work, and will doubtless make

clear a subject which in many practical minds has been more or less indefinite if not mysterious.

The more important conclusions as to treatment, to which the author comes, and to which the artisan in steel will have to come, and which are also set forth by Mr. Krupp and other steel makers who have pushed their wonderful products against the tide of "practical" conservatism into vast constructive uses, are;—

1st. Avoid local pressures in working cold steel.

2d. If local pressures must occur, remove their effects by annealing—not once, but as often as dangerous pressures are produced.

The rationale of this treatment is obvious; steel is more dense than iron, hence it must be more humored in its cold treatment. But when it once gets into working shapes without internal strains, it is much stronger and safer than iron.

It should seem that such careful, thorough and obviously trustworthy experiments as those detailed in this book, and the conclusions to which they inevitably give rise, should prove a stimulus to our steel makers, to enlarge the range of manufacture rather than to curtail production because their one specialty may possibly exceed the present demand—and to engineers and to constructors of government works, to take a leading part in all efforts to adapt the new material and its treatment, rather than to wish them well from afar off.

Any remarks on this subject would seem hardly complete without some allusion to the work of the existing U. S. Commission to test iron and steel. The work they have laid out is much more comprehensive than that detailed in this book, although it can hardly be more *thorough in* certain directions. It is intended not merely

to give the qualities of these metals as they are found in the market, but to show what compositions as well as what treatments of iron and steel will adapt it to all uses in engineering and the arts. If any class in the community should be anxious to forward this enterprise, it should be the makers of cheap steels, whose range is now so limited, and to whose products the results of these experiments must inevitably commend engineers and constructors at large.

A. L. HOLLEY.

NEW YORK, Oct. 15, 1875.

INTRODUCTION.

WITHIN the last few years, metallurgical industry has realized in the manufacture of steel, a notable progress, chiefly in the Bessemer and the Martin processes. It is now possible to obtain from these metals, plates and bars of remarkable homogeneity. Their qualities soon attracted the attention of Constructors, who have sought to bring them into general use.

Certain steels elongate and resist rupture much better than merchant irons. It is possible by substituting steel for iron, especially under tensile strains only, to notably decrease the size of the parts, and consequently the weight of materials used in construction.

Steel Works can now furnish plates of great area, and long angles and bars of regular texture, and free from the defects often met in piled iron.* The use of pieces of large dimensions dispenses with a multiplicity of joints and allows a reduction in the manufacturing expenses while it realizes a new economy in weight.

* The Creusot and Terre-Noire Works have furnished for L'Orient and Brest a great number of plates up to 75 square feet area, and angles 50 feet long. For I beams, a length of 43 feet has not yet been exceeded. Greater dimensions could be obtained, the manufacturers say, only by considerably enlarging the mill engine, a 600-horse-power engine as it now stands. They hope shortly to go beyond this limit and to reach the length of 59 feet—necessary in naval constructions.

The cost of steel—the economy that may be realized in its actual use, is not yet clearly ascertained; hence it is impossible to state that land constructions made of this metal will always be cheap. But, in the navy, the advantages in the use of steel are much more evident. A notable reduction in the weight of the frame of a ship allows a corresponding ~~increase~~ in the weight of the armament, armor-plating, machinery, load, etc. If two ships are built under the same conditions of solidity, one of iron ~~and the other of~~ steel, the latter will have qualities which are superior from several points of view.

In order to give a steel ship the ~~same~~ defensive and offensive power as an iron ship, it will not be necessary to give it the same dimensions. Either the draft, the length, or the breadth may be reduced, and either of these reductions is of great importance, whichever may be adopted.

In view of the remarkable properties of steel, the efforts of constructors to make its use general, especially in the navy, will be understood.

Unfortunately, along with these qualities, steel has shown, wherever used, some abnormal defects apparently inexplicable *à priori.* Some completely finished parts have been broken under the slightest stress, and sometimes without any apparent cause. Some plates, drilled, and ready to be put in place, when left alone for a few hours, were found cracked; others were cracked in riveting. In short, steel has evinced, especially after heating, defects, the causes of which seemed undiscernible.

People have tried to explain these facts on the theory of tempering in a current of air, the hardening influence of the ground, etc., etc. These hypotheses, which seemed

correct in a few isolated cases, were not verified under other circumstances; and the difficulty of working steel according to certain principles has in the end thrown much discredit on the use of this metal.

A few years ago, in England, steel was used to a certain extent in government ships and in the merchant navy; but its use was limited. The great insurance companies gave their sanction, making reservations at the same time. Since then, the recognized defects of steel have been such that its use has not developed as might have been expected.

In France, this metal has been used in the construction of bridges and boilers, and chiefly in the manufacture of rails. In the merchant service and in the navy its use has been limited to the manufacture of boilers, masts, boats, or small ships of little importance.

In 1873, three large men-of-war were commenced at Brest and L'Orient, according to the plans of M. de Bussy, naval engineer. Steel was to form the greater part of the construction; the frames, the internal plating, the bulk-heads, the decks were to be made of this metal. The external plating alone was to be iron. We have not dared, in the face of the defects previously attributed to steel plates, to try to fashion them to the complicated forms met in this external plating. Never had the English, nor any foreign nation employed steel on such a large scale. The designer of these three ships, and the Minister who approved the plans, boldly took a new departure. The remarkable qualities of the materials furnished by Creusot and Terre-Noire, and the method followed in the ship-building works, will certainly lead to the successful completion of these ships, and thus justify

the predictions of the author of the project, who directs the construction of the two ships built at L'Orient.*

The results obtained so far have been judged so satisfactory, that recently (December, '74) the Minister of Marine has ordered the building of three large new ships in which steel is to be used, as in the preceding ones, for the construction of all parts not in direct contact with sea water.

Work of the varied character to which plates and bars must be subjected in such constructions, has given rise to the series of researches and observations which I propose briefly to describe. I have thought that at this time, when few data on the manner of working steel are known, this statement might furnish useful information.

The composition of steel, so long disputed, seems about certain now. It was brought to light by some remarkable works, particularly those of Mr. Caron and M. Joessel, naval engineer. I have found in their works, some considerations which I have thought necessary to reproduce here. All the facts I have observed seem to closely agree with the ideas of these authors; they confirm their theory, which I have thought proper to adopt, in the actual state of our knowledge; but it must not be forgotten that like all theories, this one constantly needs to be modified by experience, and is yet far from having reached absolute certainty. Besides, I only proposed, in developing it here, to make it a convenient means of grouping the different facts stated, in order to arrive at simple and practical methods of working and manufacture.

* At the time of writing, these ships are not finished; but the greater part of the material has been worked up, fitted and riveted. All the difficult pieces are nearly done. 1,653,000 lbs. of steel plates, 22,960 ft. of angle iron, and 19,680 ft. of I beams have been made up. We are therefore certain of the success of these constructions.

CHAPTER I.

COMPOSITION OF STEEL—ITS CHIEF PROPERTIES—TEMPERING AND ANNEALING.

THE metals designated in the trade as cast iron and steel owe their characteristic properties to the presence of a certain quantity of carbon either mechanically mixed or in solution with the iron. These metals may contain other substances more or less affecting these properties; chiefly phosphorus, silicon, sulphur and manganese. But neither of these substances is necessary to the constitution of cast iron or steel. It is sufficient to mention that they are present in most of the irons of commerce, without studying the considerable influence they may exert.

Putting aside, then, all considerations relating to the presence of foreign matters, cast irons and steels are carburized irons. Carbon exists in them either in a state of solution or of mixture, without forming any clearly defined carburet.

" Steel is a solidified solution of carbon in chemically pure iron. This solution in a liquid state is not saturated except in case of the steel which contains the maximum of carbon which iron can hold in solution. Cast iron is a saturated solution of carbon in iron, with an excess of carbon in a state of mechanical mixture. It might be defined as steel containing carbon in mechanical mixture. In this state (mixture)

the amount of carbon is larger, in proportion as that held in solution is smaller, or as the total quantity of carbon contained is greater. So grey cast iron is a slightly carburized steel with much carbon mixed, and white cast iron is a more carburized steel with less mixed carbon."*

The phenomena of the solution of carbon in iron to form steel, group themselves around the four following principal laws:

1. The quantity of carbon iron can contain in solution is greater as the temperature increases.

2. By slow cooling, part of the carbon is separated from the solution and remains in a state of mixture.

3. By rapid cooling or by a sufficient external pressure, the greater part of the carbon is maintained in solution. Rapid cooling acts in this case by the pressure resulting from it. If the carbon is mixed, an external pressure produces a solution in greater or less proportion according to its intensity.

4. The temperature at which melted steel is solidified decreases in proportion to its richness in carbon.

These laws of the solution of carbon in iron conform to those which regulate the solubility of solids and gases in liquids.

1st. The solubility of solids generally increases with the temperature.

2d. When a solution made at a high temperature is cooled, part of the solid is separated.

3d. The solution would probably maintain itself under a sufficient pressure; but no experiment has been made on this subject, to my knowledge; a trial, to verify this point, would probably be very difficult of execution, on account of the enormous pressure required. The solubility of gases increases with the pressure.

4th. Finally, solutions are generally solidified at temperatures decreasing as the solutions become more intense.

* Expériences sur les fers, les fontes et les aciers. JOESSEL, Naval Engineer.

The rapid and slow cooling of heated steel constitute tempering and annealing, two operations which play an important part in the use of the material.

When any metal is tempered, that is to say, rapidly cooled, the external layer cools first, and it does this all the quicker as the difference in temperature between the body and the liquid in which it is immersed is greater. The conducting power of the liquid used has also a great influence on the rapidity of cooling: tempering in mercury, for instance, will be more intense than tempering in water.

This cooled external layer contracts and presses strongly on the inside, which is yet at a high temperature; reciprocally, it receives from the inside the same pressure. Another phenomenon is a consequence of this contraction; in order to contain the internal volume, the external layers must stretch at the expense of their elasticity; if the tempering has been intense enough they may exceed their limit of elasticity and stretch permanently. If tempering has been incomplete or slight, this limit not being reached, the extension will be but momentary, and will disappear when cooling is complete.

It is known that these phenomena are practically taken advantage of, to break cast iron blocks, which could not be easily effected by blows; they are heated red and cooled in a stream of water. The external surface contracts and passes its elastic limit; as it is capable of only slight stretching before breaking; cracks show themselves on the surface, and a comparatively light blow is sufficient to break the block into several pieces.

During the second period of tempering, the cooling spreads to the centre. In their turn, the central fibres contract on account of the lower temperature; but they are bound to the external fibres which have exceeded their limit of elasticity; they must then stretch at the expense of their elasticity as they contract; they, at the same time, cause a contraction of the external fibres.

A tempered body is therefore subjected to direct forces which are balanced by molecular tensions. The forces which exist after tempering can be exhibited by suppressing a part of them. If a bar of tempered iron, squared on all sides, is cut in two longitudinally in a planer, care being taken to hold it in an invariable position, each of the pieces assumes, when left to itself, a curved form, the concavity of which is on the planed side. This form demonstrates a tenison in this part, resulting from the second period of tempering. The forces brought into play in the first period would have produced the opposite effect if they alone had acted.

Bodies increase in volume when they are tempered. M. Caron has observed the following variations of steel bars:—

TABLE NO. I.

	NATURAL STATE.	AT RED HEAT.	AFTER TEMPERING.
Length	20.00	20.32	19 95
Width	1.00	1.03	1.01
Thickness	1.00	1.03	1.01
Volume	20.00	20.557	20.351

In these bars the length decreased and the width and thickness increased; under the influence of an internal pressure the bar behaves like any homogeneous body subjected to deformation by an internal force; it tends to assume the spherical form.

M. Caron mentions another instance of a bar of rolled steel:

TABLE NO. II.

	NATURAL STATE.	AFTER TEMPERING.
Length	20.00	20.45
Width	1.51	1.51
Thickness	3.70	3.70
Volume	111.74	114.25

In this example tempering has again produced an increase of volume; but unlike the preceding case, the greatest dimension has increased and the others have not changed. This contradiction is apparent only. It is explained by the lack of homogeneity in a rolled bar which is capable of stretching more readily in the direction of the rolling, than perpendicularly to it. The longitudinal fibres exceed their elastic limit before this limit is attained transversely; the addition to the volume consists in increased length.

Tempering should produce these effects in homogeneous bodies only, the composition of which does not vary with temperature and pressure. In steels and other carburized irons tempering is complicated by the presence of carbon, the solution of which it partly brings about. It is difficult to know whether the increase in volume observed in tempered steel is to a certain extent modified by this solution; by continuing the comparison between the laws of solubility of solids in liquids, we may suppose that the increase in volume does not result from this cause; for a solution never has a larger volume than the total volume of the bodies it contains.

The solution brought about by tempering steel produces a body endowed with properties different from those it possessed before tempering; but this body, at the time of sudden cooling, is always under the influence of the phenomena we have just explained. The pressure resulting from the two phases of tempering maintains in solution a part of the carbon that would have become separated by slow cooling; this portion will be greater as the pressure is stronger, and the tempering more rapid.

If a non-homogeneous body is tempered, composed for instance of steels at different degrees of carburization, the action will be complex; it seems probable that, when the body is hot, the carbon will be distributed a little less irregularly, and that this dissemination can increase only under the pressure of the cooled external fibres. If we suppose this body repre-

sented by different tints according to its amounts of carbon in different parts, the lines of demarcation, instead of being decided as in the original state, will be blended after tempering.

This phenomenon of transfusion of carbon through iron or steel heated to a sufficient temperature is well known. A bar heated with charcoal is cemented, or dissolves carbon first on the surface, then more deeply, and finally to the centre, if cementation lasts long enough.

When steel is subjected to different degrees of tempering, the carbon is kept in solution in a much larger proportion, as tempering is more energetic. With each class of steel, there should correspond a degree of temper at which the maximum effect is produced, that is to say, when tempering would cause the solution of all the carbon contained in the steel. If the effort of contraction were the same for all steels, the intensity of temper producing this effect should increase with the degree of carburization. But the contraction or pressure due to rapid cooling is generally insufficient to produce this result. The more the rapidity of cooling is increased, the more the steel changes its properties. The least carburized steels only could be excepted; beyond a certain point the solving effect produced by an increase of intensity in tempering ought to be nothing; alternations in elasticity only could be observed. But, in these bodies, the limit of elasticity is reached under relatively slight effects, and tempering, by a variation of temperature such as we can effect, does not produce a sufficient pressure to dissolve all the carbon.

Tempered bodies generally regain their properties when they are annealed, that is to say, when they are made to cool slowly after having been heated sufficiently. When a homogeneous body, the composition of which does not vary by heating, is annealed, the effect is merely to restore its original elasticity. To insure thorough annealing, the operation must be performed at a sufficiently high temperature, and the cooling must be slower as the size of the body is greater, so that

there may be between the interior and exterior, but a slight difference in temperature. The first condition is necessary to allow the metal to recover the elasticity it lost in tempering; the second condition should prevent in the successive phases of cooling, the production of undue strains.

In complex bodies like steel, the effect of annealing is complex; besides this restitution of elasticity to the fibres altered by tempering, it produces the separation of a part of the mixed carbon. This separation must take place equally throughout the mass to render the bodies homogeneous after annealing; and it is easily understood that a very slow cooling is necessary to insure this result. For large pieces of steel, this cooling must occupy several days, sometimes several weeks.

When steel is properly annealed, the different molecular tensions previously produced are suppressed; the fibres relax under the influence of heat, and return to their first elasticity.

If annealing is applied to a piece having undergone local tempering, the effect will be the same. In a bar made up of steels of different degrees of carburization, annealing will establish a little more homogeneity. Owing to the high temperature the bar will have to bear, the lines of demarcation will no longer be as clearly defined, and the difference between the several parts will be less, as the piece is exposed longer to the fire. In annealing, this more regular dissemination of carbon is due only to the high temperature to which the piece is raised, while in tempering, the effect is increased by the pressure resulting from rapid cooling.

Annealing must not be performed at too high a temperature,—near the melting point,—lest the fibrous texture of the metal acquired by forging, should be changed; slow cooling would crystallize it, and it would then have no elasticity,—it would be burned.

In the same steel there may exist a series of intermediate

states between the natural state and the state corresponding to the maximum temper it can take. The several properties of the same steel follow a continuous law of variation between these two extreme points. In the natural state, steel possesses a hardness increasing as it contains more carbon and as it approaches more and more the maximum of saturation. Tenacity, or resistance to breaking follows the same law, increasing in a continuous manner from soft iron to the hardest steel.

The stresses steel can bear before reaching its limit of elasticity follow the same law. On the contrary, the attainable stretching increases when the quantity of carbon and consequently the hardness and tenacity increase. The welding properties vary like the stretching qualities; they are very high in slightly carburized irons, and are reduced to almost nothing in steels rich in carbon.

When steels are tempered under the same conditions, hardness, tenacity and stretching follow the same law that obtains in the natural state; hardness and tenacity increase with temper, and ductility decreases. In short, the difference between a steel in the natural state and the same steel tempered is less as carbon decreases and as the metal approaches pure iron.

We will consider here, only temper obtained by rapidly cooling steel heated to a high heat in a cold liquid. Under these conditions the changes of constitution induced by tempering should decrease as the operation is performed on less carburized steels. With very high steels, the elastic limit is reached under a very heavy load only; with soft steels the elastic limit is much more quickly attained; the same degree of cooling will then produce a contraction and pressure much smaller in the second case than in the first.

From this statement we may conclude that, whenever hardness and tenacity are required, and a material liable to deformation before breaking is not desirable, the highest or most carburized steel must be used; from this class is chosen

the steel for tools that are not worked under blows. For constructive purposes where a more elastic material is needed, less carburized iron, in other words, soft steel must be used.

We can conceive that tempering followed by annealing might be used to improve certain more or less carburized iron, especially to restore homogeneity lost in the different stages of manufacture.

All merchant irons contain slight quantities of carbon, and consequently yield, but in a less degree, to the influences of tempering and annealing. Heat produces in iron, a more complete solution of the carbon and a dissemination of that mixed in the metal; probably also of other foreign ingredients. The pressure which follows tempering increases this dissemination. Finally, while annealing, the heat continues the effect produced, and slow cooling allows the molecules to group themselves so as to nearly remove the several internal strains.

In a great many cases tempering is followed by such an incomplete annealing as tends to lessen the molecular tensions, while preserving in the metal the greater part of the properties due to tempering, viz., hardness, tenacity, and also a more homogeneous composition. Aftewards more or less annealing is given according to the degree of elasticity which is to be restored.

Partial annealing after tempering is used in armor plates. The tempering they undergo after rolling renders them more homogeneous throughout their mass, by the compression it produces in every direction. Hardness, or resistance to the penetration of projectiles is increased, but the metal becomes brittle, as the tempering is more complete, or, with the same range of temperature, as the plates are thicker.

Complete annealing would destroy all brittleness; but in order to preserve some hardness and prevent any internal crystallization, annealing is carried only to dark red; this temperature is insufficient to restore to the different fibres, all

their elastic properties, but it allows a preservation of the greater part of the hardness proceeding from tempering.

In plates measuring less than 20 centimetres (.787 in.) in thickness, this annealing is sufficient for the purpose mentioned; the result is a metal able to withstand the penetration of projectiles and rarely breaking under their impact. In thicker plates submitted to tempering and annealing under the same conditions, the molecular tensions after tempering preserve more value after annealing; the plates satisfactorily resist penetration; they however, have considerable brittleness. To avoid this defect, it would be necessary to give more intensity to annealing; the plates would then offer less resistance to penetration, but they would no longer break under blows.

The same result ought to be attained by reducing the intensity of temper; the heat to which the plates have to be raised cannot be lessened, since, in order to obtain homogeneity, a solution of all foreign matters in the iron must be produced; but the rapidity of cooling can be diminished by using a liquid which is a less good conductor than water, or by raising the temperature of this water. By this latter means the heated piece will be subjected at first to a rapid cooling to prevent separation of the carbon from its solution, then a much slower one, to prevent extreme molecular tensions.

These considerations are verified by M. Caron's recent researches. In laboratory experiments he has succeeded in bringing to the same degree of hardness, tenacity and elasticity, some steel springs tempered and annealed by the ordinary process, and others simply tempered in hot water. He expresses himself as follows, upon his experiments:

"Tempering in hot, or rather boiling water singularly modifies soft steel containing from $\frac{2}{1000}$ to $\frac{4}{1000}$ of carbon; it increases its tenacity and its elasticity without sensibly altering its mildness."

M. Caron, in experiments reported in the same article,

succeeded in regenerating burned iron by tempering it in a hot liquid; he used a solution of sea salt heated to 110 degrees centigrade. The primitive texture is then restored to the metal by the strong pressure due to tempering and the drawing out of the fibres which results from it. The slow cooling following this first effect, allows the fibres to recover the greater part of their elastic properties, notwithstanding the previous rapid cooling. It is well known that burned iron is restored by raising it to a white heat and submitting it to an energetic hammering. It will be seen that tempering acts the same as hammering; it constitutes a real forging action, producing a drawing out of the metal. It follows from this that the quality of cast ingots might be improved by a series of temperings which would bring them to the same state as if they had undergone a preliminary forging or rolling. We have not been able to verify this deduction, not having steel ingots at our disposal.

CHAPTER II.

CLASSIFICATION OF STEELS—SOFT STEELS USED AT L'ORIENT AND BREST—TESTS.

The various properties of steels—their resistance, their stretching, the manner in which they are affected by tempering—furnish a convenient way of comparing and classifying these metals; it would be difficult to do so, practically, by taking their composition as a basis.

Until a few years ago, steels more carburized, and much more liable to the defects pointed out above, than the very soft metal now manufactured, were generally used. The substitution of ferro-manganese for spiegel, to produce carburization at the end of the Bessemer process, or in the Siemens-Martin furnace, has contributed to the production of materials containing very small quantities of carbon, though free from the oxydes of iron that the manganese was designed to reduce or remove. To distinguish this steel from the one they had previously put in the market, the manufacturers have given it the name of *métal fondu*, or *cast metal.*

The steel used in France and England in building large ships may always be classified among soft steels; but France alone has so far, we believe, worked cast-metal on a large scale.

The constructors of the English navy demanded for their steel plates a tensile resistance of 32.9 tons per sq. in. in the direction of the fibre, and 29.8 tons perpendicularly to the fibre.

The resistance should in no case exceed 39.9 tons per square inch.

TABLE NO. III.

CLASSIFICATION NUMBER.	A. CLASS.						B. CLASS.						C. CLASS.					
	NON-TEMPERED.			TEMPERED.			NON-TEMPERED.			TEMPERED.			NON-TEMPERED.			TEMPERED.		
	Load corresponding to.		Percentage of extension at rupture.	Load corresponding to.		Percentage of extension at Rupture.	Load corresponding to		Percentage of extension at rupture.	Load corresponding to.		Percentage of extension at rupture.	Load corresponding to.		Percentage of extension at rupture.	Load corresponding to.		Percentage of extension at rupture.
	Rupture.	Elastic limit.		Rupture.	Elastic limit.		Rupture.	Elastic limit.		Rupture.	Elastic limit.		Rupture.	Elastic limit.		Rupture.	Elastic limit.	
	Tons p sq. in.	Tons p sq. in.		Tons p sq. in.	Tons p sq. in.		Tons p sq. in.	Tons p sq. in.		Tons p sq. in.	Tons p sq. in.	Tons p sq. in.	Tons p sq. in.	Tons p sq. in.		Tons p sq. in.	Tons p sq. in.	
1	48.31	24.72	13	74.16	45.64	.2	49.26	26.05	13	75.64	48.06	3.8	50.08	27.39	13	77.98	53.89	.5
2	46.67	23.96	15	70.05	43.30	4.8	47.49	25.36	15	72.91	47.87	5.7	48.31	26.75	15	75.00	51.99	6.6
3	44.57	23.07	17	66.95	41.71	7.2	45.52	24.88	17	68.47	45.01	7.8	46.40	25.99	17	71.00	49.45	8.6
4	43.61	22.12	19	61.37	38.42	9.4	36.90	23.74	19	62.76	41.46	10.2	44.25	25.23	19	66.44	45.96	10.8
5	39.81	21.04	21	56.17	35.63	11.1	40.83	22.70	21	57.70	39.37	12.6	41.78	24.28	21	62.76	43.62	13.3
6	36.77	19.65	23	49.89	31.90	13.2	37.85	21.42	23	51.99	34.87	14.8	38.99	23.14	23	56.93	39.43	16.0
7	33.72	18.25	25	43.49	27.77	14.6	34.87	20.16	25	46.79	31.57	17.0	35.00	22.06	25	51.48	36.08	18.2
8	31.19	16 86	27	38.80	23.96	18.0	32.01	18.76	27	41.72	28.34	19.5	33.09	20.73	27	46.02	34.46	20.6
9	28.53	14.26	29	35.63	21.30	21.0	29.60	17.43	29	37.28	25.36	22.0	30.56	19.46	29	40.45	28.72	23.4
10	....	....	....	....	....	....	26.18	14.96	32	32.84	20.92	24.2	27.58	17.62	32	33.73	23.58	27.6
11	....	....	....	....	....	....	....	....	....	....	....	....	24.92	15.47	35	29.16	20.79	33.0

The above Loads are in tons per square inch.

For the ships built at L'Orient and Brest, where cast-metal alone has been used, the minimum tensile resistance required was 28.5 tons per square inch, with a corresponding stretching of 20 per cent at least. For deck beams made up of I bars, $11\frac{13}{16}$ in. deep, the lowest limit of stretching was put down to 18 per cent. in consideration of the difficulties of manufacture. The plates were furnished in nearly equal quantities by the works at Creusot and at Terre-Noire. The I beams were manufactured by MM. Marrel Bros. of River de Gier from Terre-Noire steel; the other rolled bars and beams were furnished by the Creusot works.

The steels were manufactured at Terre-Noire by the Bessemer process and at Creusot by the Siemens-Martin process. Both these great works have succeeded by means of numerous tests, and the certainty of their manufacture, in furnishing soft steels of obviously even quality. They can however vary, at the wish of the buyer, the properties of their products. The table No. III is taken from a classification recently adopted by Creusot, of all the steel this establishment

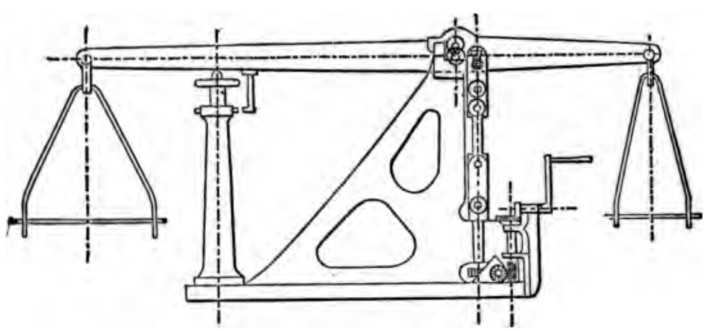


Fig. 1. Scale for
Measurement of tensile strains.

furnishes to order. The figures given in this table are the result of a great many trials; nevertheless, they are given

only as indicative and comparative. The bars subjected to test were all turned to 3.93 in. in length, the section being 0.31 square in. Tempering was done in oil, the bars being heated as uniformly as possible to a temperature corresponding to bright red.

The steel furnished to the Government works at L'Orient and Brest, offering a minimum tensile resistance of 28.5 tons per square in. was to reach its limit of elasticity only under a heavier load than 13.94 tons. Estimating that iron plates reach this limit of elasticity under a load of 10.4 tons per sq. in., which is rather above the average, it will be found that, in construction, an iron plate of thickness e' can be replaced by a plate of thickness e' determined by the relation :—

$$22\,e' = 16.5\,e, \text{ or } e' = \tfrac{3}{4}\,e.$$

This is the case only when the plates suffer a direct tensile strain. An iron plate 0.47 in. thick can then be replaced by a steel plate 0.35 in. thick.

At L'Orient, all the tensile tests on Creusot or Terre-Noire steel were made with a scale built by M. Frey, having a range of 0 to 25 tons (fig. 1). The test bars, a sketch of which is given in fig. 2, were brought to a uniform section for a length of more than $7\tfrac{7}{8}$ in. Each end was wider than the body, and these different widths were connected by easy curves. In the outline, great care was taken to avoid any angle in which a rupture might originate. At each end holes were drilled allowing the bars to be connected to the jaws of the testing-machine by heavy pins. The beam of the scale was always kept horizontal for this purpose, the lower fixed point of the bar was moved down while the stretching was taking place. The tensile strains were obtained

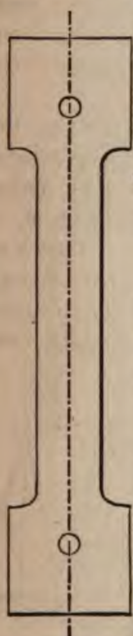


Fig. 2.
Test bar.

by loading successively one or the other scale beam; they where gradually increased, 44 lbs. at a time, leaving a certain interval of time between each increment of load to give to the successive elongations time to develop themselves.

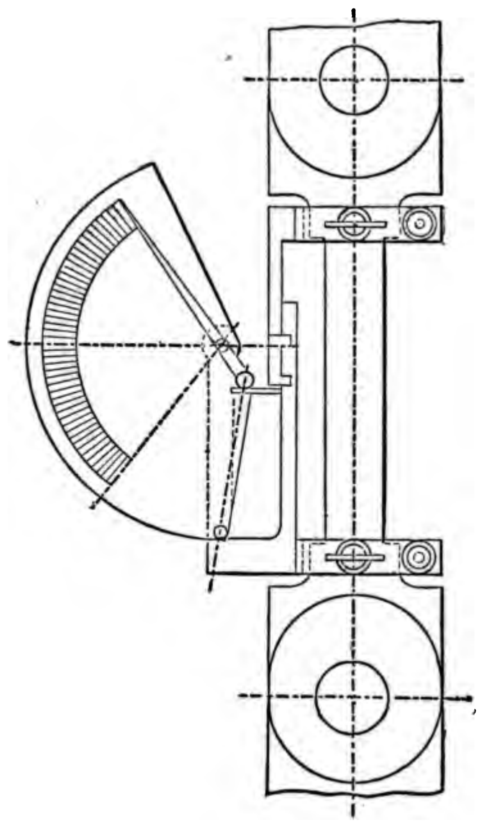


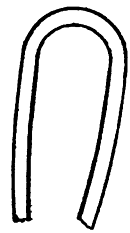
Fig. 3.
Measurement of elongation.

To ascertain the limit of elongation a length of 7 in. was defined by two centre-punch holes; on these marks were fixed the extremities of a small apparatus (fig. 3); this apparatus was

frequently applied, and indicated by its graduation the successive elongations. An observer followed the travel of the index, and noted after each rupture, the figure given by the instrument, also the load put on the scales. These tests were always made by the same men.

4.—Bessemer.
Natural State.

5.—Martin.
Natural State.



6.—Bessemer.
Tempered.

7.—Martin.
Tempered.

8.—Bessemer.
Tempered and annealed.

9.—Martin.
Tempered and annealed.

Besides these tests of tension, the toughness of the metal was frequently ascertained by bending strips cut from plates or bars; this was done by hammering only on the extremities of the specimens and never where flexion was taking place; the bending was stopped when the first crack appeared and the results obtained were noted and kept as a basis of comparison. Sometimes the bending was done under a hydraulic press, thus allowing work without blows; the specimens so tried gave the same curves as those bent by the hammer under the conditions just described.

The Steels from Creusot and Terre-Noire subjected to these different tests did not give the same results; it was therefore important to repeat them, in order to determine the relative value of the products.

The grain of the metal (as shown by fracture) indicated at first sight, a slight difference; in order to examine it, nicks were made in plates and beams with a chisel; the use of a sledge was avoided, as it might have altered the grain; the specimens were then broken as usual by bending. The Bessemer metal showed a very fine grained break, slightly slate colored, and approaching the fracture of steel proper; by tempering, the grain became still finer, the color or brightness not varying sensibly. In I beams, the grain was a little more steely than in the plates. The Martin metal from Creusot gave a finer grained fracture, whiter and brighter; it approached more by its brightness and color the fracture of fibrous iron; tempering did not modify it in a very appreciable manner. In every case the grain evinced the greatest homogeneity, at every part of its surface.

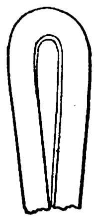
Some strips were cut on a planer from plates from both makers; the mean deformations (fig. 4) were obtained on a series of Bessemer plates, and (fig. 5) on a series of Martin plates.

Figs. 6 and 7 give the mean deformations obtained after tempering, and figs. 8 and 9 after tempering and annealing. Tempering was done by heating the plates to cherry-red and dipping them into water at 50° Fahr. Annealing was obtained by heating to cherry-red. These experiments were made on specimens 0.31 inch thick for Bessemer metal and 0.35 inch thick for Martin metal; the trial was consequently a little harder for the latter.

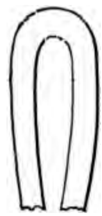
Martin steel bore the bending test in the natural state, a little better than Bessemer steel; the difference was slight, but very decided after tempering, and we notice from this stand-point a marked inferiority in the products from Terre-

Noire. Finally, after annealing, elasticity was obviously restored to what it was before tempering.

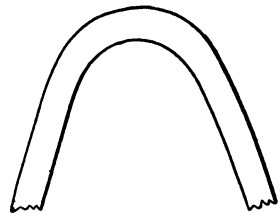
Strips cut out of I beams gave in the natural state, the



10.—Fers en H. (Flanges, Natural State.)

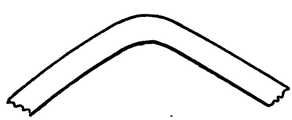


11.—Fers en H. (Web, Natural State.)



12.—Fers en H. (Flanges Tempered.)

average deformations, fig. 10, when cut from the flange, 0.53 inch thick on the average, and fig. 11 when cut from the web, 0.42 inch thick. After tempering, cracks were observed when the specimens were of the form fig. 12 for the first, and fig. 13 for the others. The I beam metal, chiefly in the region of the web, seems to experience by tempering an alteration in elasticity much more prominent than that observable in Bessemer plates under similar circumstances.



13.—I beam Web Tempered.

Two series of tensile tests made on plates, angles, and I beams gave the following average results:

TABLE IV.

UNTEMPERED STEEL.

	RESISTANCE TO RUPTURE PER SQ. INCH OF THE ORIGINAL SECTION.	PER CENT. OF STRETCHING.
Bessemer Plates	31.60	20.2
Bessemer I Beams	32.81	19.5
Martin Plates	28.69	24.1
Martin Angles	29.00	21.7

TABLE V.

	Resistance to rupture in tons per sq. inch of the original section.		Per cent of stretching.	
	Lengthwise.	Crosswise.	Lengthwise.	Crosswise.
Bessemer Plates	30.95	30.83	22.9	21.9
Martin Plates	29.88	30.07	24.2	23.5
Bessemer I Beams.......	33.39		21.1	
Martin Angles..........	30.45		24.5	

A few more tensile tests after tempering were made at L'Orient. Tempering was done in the manner described above for the trial strips.

The result was as follows:

TABLE VI.

	Resistance to rupture in tons per sq. inch of the original section.	Per cent of stretching.
Bessemer Plates	44.22	
Bessemer I Beams..............	47.69	6.4
Martin Plates	34 58	

A few more tensile tests were made after tempering and annealing. It was observed that annealing, well done, restored to the metal in every case its previous tenacity and elasticity, as modified by tempering.

Finally, by trying these different products with a file, it was noticed that the I beams were the hardest to cut; then came the Terre-Noire plates; the Creusot plates and angles were obviously softer than the preceding. After tempering hardness could be classified in the same order.

We may then conclude from these different experiments that the Terre-Noire steels have more resistance to rupture,

more hardness and less elasticity than the Creusot products; they are much more modified by tempering; in short they evince the characteristics of more carburized iron. Moreover, the rolled beams seem a little more steely than the plates from the same origin. It is hard to explain this fact, without knowing all the circumstances attending manufacture. It may be that the plates undergo in the heating furnace a more decided decarburization than the beams; the thin plates present in the last heatings, with the same volume, a larger surface to the action of flames that may be slightly oxydizing.

CHAPTER III.

TREATMENT COMMON TO PLATES AND ROLLED BEAMS. PUNCHING, DRILLING, SHEARING, HAMMERING, ETC.

THE manipulations to which the materials used in ship-building must be subjected are very numerous. Some are common to these materials under whatever form they are used. We will examine first the effects of the various operations on soft steels, beginning with punching. We will then study the divers processes specially applicable to plates, then to angles, and finally to I beams.

Punching, from experiments heretofore made, is supposed to alter notably the tenacity of steel. Numerous experiments made on this subject in England, are mentioned in Mr. Reed's work on the construction of iron and steel ships. The author, taking these experiments as a basis, recommends the almost exclusive use of drilling; he, however, indicates several ways to lessen the alteration produced by punching, such as annealing, and the use of dies of a larger diameter than the punch.

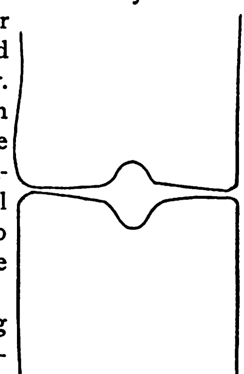
The tensile tests made at L'Orient on punched Terre-Noire plates proved from the start that, with the adopted mode of experimentation, the width of the trial bars exerted a great influence on the tenacity. The following results were obtained from Terre-Noire plates 0.27 in. thick; the test-pieces were punched in the middle, the hole being 0.66 in. and the die 0.76 in. for some, and 0.82 in. for others. In the first case, the holes were cylindrical, and in the second conical.

TABLE VII.

WIDTH OF THE SPECIMENS.	RESISTANCE TO RUPTURE PER SQUARE INCH.			
	Cylindrical Punching.		Conical Punching.	
	In the direction of fibres.	Across fibres.	In the direction of fibres.	Across fibres.
in.	tons.	tons.		
1.24	27.00	26.96	31.73	32 17
1.95	25.89	26.33	28.23	27.47
2.65	25.25	23.54	26.27	24.23
3.35	22.65	23.54	22.31	24.23
4.05	24.23	23.54	22.91	24.23
4.75	23.09	23.54	23.73	24.23

From this table, we first observe that the resistance in the direction of the fibres and across them is sensibly the same. This is also shown by a great number of tensile tests made at the Works and indicated in the preceding chapter. Stretching is also the same in both cases. In the following statement, we will make no distinction between lengthwise and crosswise resistances. All the trial strips hereafter referred to were tested in the direction of the length of the plate.

The results noted in the preceding table imply a decided apparent alteration due to punching. In the widest strips resistance to rupture seems to be reduced 30 per cent.



Scale .

14.—Form of Fracture.

We further remark:

1st. That tenacity, seems to diminish in both varieties of punching as the width of the strips increases.

2d. That conical punching does not seem to affect sensibly

the narrow strips, while cylindrical punching always affects them in a notable manner.

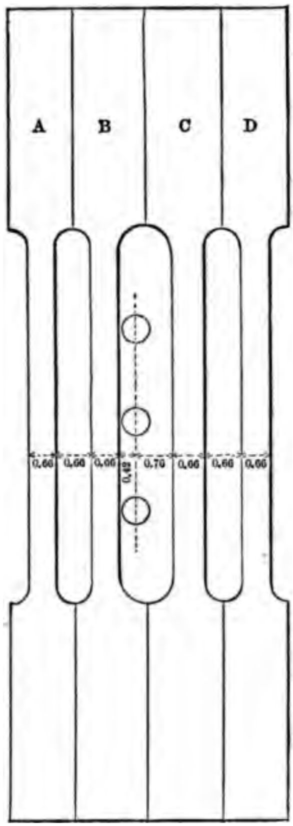


Fig. 15.

3d. That the effect of both modes of punching seems to be the same on wider strips.

The alteration due to punching cannot then affect the tenacity of the metal, for the narrowest specimens ought to resist the least; these results however may be attributed to alteration in elasticity. This explanation seems all the more plausible as, in the wide specimens the form of the fracture (fig. 14) proves that the central fibres stretched less than the others, and indicates a rupture beginning at the centre.

We were then led to investigate whether the elasticity of the fibres around the hole was altered, and if so, what the extent of this altered zone was. For this purpose, 4 series of strips (fig. 15) were traced on a Terre-Noire plate.

Between two series, cylindrical holes were punched (0.66 in. punch and 0.70 in. die), and between two others, conical holes (0.66 in. punch and 0.80 in. die); these holes were about as far apart as needed for a water-tight joint. In each series, 4 test strips were cut as per outline of figure, in such a manner as to be parallel to the line of holes, and at different distances from the holes.

TABLE VIII.

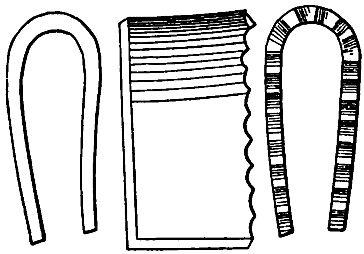
MARKS ON SPECIMENS.	RESISTANCE TO RUPTURE PER SQUARE INCH OF ORIGINAL SECTION.		PER CENT. LINE OF STRETCHING.	
	Cylindrical.	Conical.	Cylindrical.	Conical.
	tons.	tons.		
A.	31.54	30.57	21.5	19.0
	31.48	31.89	21.5	22.0
B.	30.70	31.02	22.0	21.5
	30.89	30.89	20.0	22 0
C.	30.70	30.70	22.0	21.0
	30.70	30.89	20.0	21.0
D.	31.32	31.16	20.0	20.0
	30.89	31.73	22.0	20.5

These experiments prove that neither stretching nor tenacity were altered in the parts subjected to stress. It might have happened, however that the alteration in elasticity, taking place in a region concentric to each hole and reaching but slightly into the bars B or C, was not notably perceptible in the preceding trial. It was attempted to produce in new specimens from the same plate, an alteration as complete as possible, by cutting them on the edge with a square punch. After punching, from 0.058 to 0.078 in. were taken off with a file on each side, so as to make the edges straight. These strips being broken, gave a mean resistance of 30.45 tons per sq. in. and a mean stretching of 21.2 per cent. It thus became evident that the alteration in elasticity, if it exists, is felt sensibly only in the region about 0.058 inch wide surrounding the punch holes, and not made manifest in the preceding trials.

Experiments as to deformation by bending, proved that elasticity was decidedly altered in this region. Specimens of Bessemer plate being sheared on one side and cut out with punch holes on the other, attained the deformation shown in fig. 16. Cracks always showed themselves on the edges, especially on the punched edge; never in the middle. By

comparing this bending with that obtained on planed Bessemer plates (Fig. 4.) it will be seen that the effect of punching is to lessen the elasticity of the metal in the neighborhood of the point where it is applied.

This altered region ought not, from the preceding experiments, to have extended further than 0.058 inch from the edges. The question whether the removal of the part immediately surrounded by the punch hole removed the cause of these defects, was investigated. New specimens were taken from a Terre-Noire plate and punched with a 0.66 in. cylindrical hole and 0.70 in. die, this hole was enlarged with a drill, so as to take away a ring of metal 0.039, 0.078 and 0.0117. inch thick, thus giving holes 0.738, 0.816 and 0.894 inch in diameter. By breaking them the following results were found:



16.—Bessemer (Natural state).

TABLE IX.

WIDTH OF THE SPECIMEN.	FINAL DIAMETER OF THE HOLES.	RESISTANCE TO RUPTURE PER SQUARE INCH OF ORIGINAL SECTION.
in.	in.	tons.
1.95	0.738	32.23
1.95	0.816	31.85
1.95	0.894	32.30

Thus, specimens of the same width (1.95 in.) gave a resistance of 25.88 tons with 0.66 in. punched hole (see table VII.) and more than 32 tons with the same hole enlarged by 0.078 in. The removal of this annular ring of metal 0.039 inch wide, surrounding the hole, thus removes the space of weakening due to punching.

This experiment, being very important, was repeated first with 0.31 inch plate. In the same Terre-Noire plate, strips 2.34 in. wide were cut out and cylindrical holes, 0.70 inch in diam. were made; some of these holes were bored; others were punched 0.63 inch wide and enlarged to 0.70 in. by boring. In both cases specimens apparently identical were obtained in the end. The average resistances to rupture were thus: drilled hole 31.22 tons per sq. in. punched and drilled hole 30.20 tons per. sq. in.

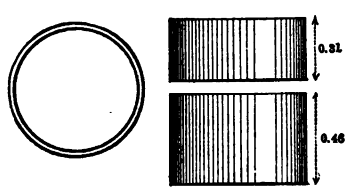
Other specimens taken from thicker Terre-Noire-plate, (0.46 in.) gave the followinig average results:

TABLE X.

		WIDTH OF SPECIMEN.	RESISTANCE TO RUPTURE PER SQUARE INCH OF ORIGINAL SECTION.
	in.	in.	tons.
Drilled holes	0.66	1.75	34.65
Punched "	0.66	1.75	27.78
" "	0.58	1.75	34.02
Enlarged to	0.66	1.75	
Punched	0.50	1.75	33.51
Enlarged to	0.66	1.75	

It is therefore thoroughly demonstrated that plates from 0.27 in. to 0.46 in. thick escape the injurious action of the punch by the removal of an annular ring 0.039 in. thick, surrounding the holes.

It was interesting to specially examine this region around



Full Size.

the holes. In one end, holes of the same diameter were put

through some Terre-Noire plates 0.31 and 0.46 in. thick—some drilled, and others punched and enlarged by 0.078 in. The part outside of the region referred to was then taken away, and by proceeding cautiously in the lathe, rings about 0.190 in. thick were obtained (fig. 17). By trying to flatten these rings, very different results were observed. The rings with

Full Size.

18.—Drilled hole. 19.—Drilled hole. 20.—Punched and reamed hole.

drilled holes were completely flattened under the hammer without any cracks (fig. 18); in trying to bring them back to their original form, a crack showed itself at each extremity (fig. 19). The rings with reamed punched holes stood the

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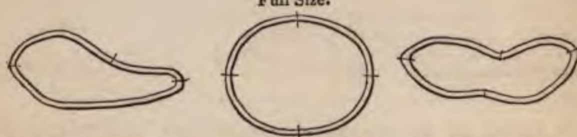


21.—Punched and reamed hole. 22.—Punched hole. 23.—Punched hole.

same test as well; (fig. 20); the first crack showed itself when, in opening the ring, the form fig. 21 was reached.

In the light of this experiment, the rings obtained either way were in the same physical condition. As to rings with punched holes not reamed, it was necessary to exert a greater effort than on the others to begin the flattening; they would sustain an insignificant deformation only, and traces of cracks showed themselves immediately (fig. 22). Figures 23, 24 and 25 represent some of these rings after complete rupture; it will be observed that each of these fragments preserves the form of an arc of the original circle. It was observed that

these last rings were harder to cut with a file than the first ones, and that they slightly scratched the plate to which they had belonged; the rings obtained by drilling or by reaming

Full Size.

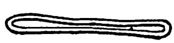
24.—Punched hole.

25.—Punched hole.

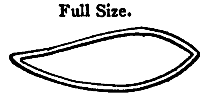
punched holes did not produce this effect. The punchings behaved under the file, in the same manner as the metal surrounding them.

Rings made with punched holes were heated in a gas furnace to cherry-red; they were allowed to cool without disturbance, and were submitted to the same test of deformation; every one was completely flattened (fig. 26); cracks only showed themselves, when after flattening, they were brought back to form fig. 27. Other rings, heated in the same man-

Full Size.



26.—Punched hole annealed.



27.—Punched hole annealed.

28.—Punched hole annealed developed.

ner, cut on a generating line, were completely developed and bent again so as to cause the interior of the ring to extend; they were then flattened as in fig. 28 without any perceptible crack. In pressing the deformation further, cracks appeared. This last experiment shows conclusively that the punch by its action, does not produce any kind of crack on the edges of the hole. Some authors have adopted the hypothesis of incipient cracking, to explain the feeble resistance observed in punched plates.

The Martin plates from Creusot were effected by punching in about the same manner as Bessemer plates. Strips of

Martin steel having one edge cut by shearing and the other by punching, were submitted to trials of deformation. They began to show traces of cracks when they had reached forms the average of which is represented in fig. 29. The cracks

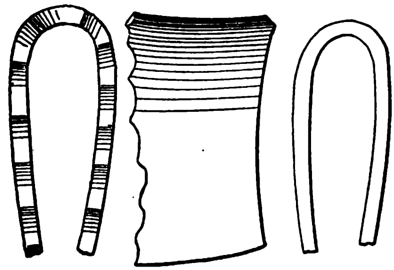


Fig. 29
Natural State.

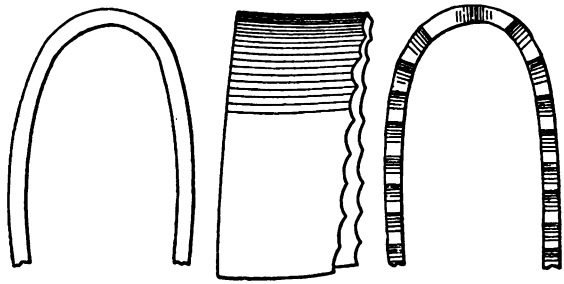
were seen about at the same time on each edge: the strips of Martin plate were 0.35 in. thick; the Bessemer strips were only 0.31 in. thick; taking this difference of thickness into account, it appears that shearing and punching act about similarly on both kinds of plates. Strips of Martin steel 2.34 in. wide with a punched hole in the middle, broken in the testing machine, gave a mean resistance of 21.89 tons per square in. Strips of the same plate of the same width, with drilled holes in the centre gave a resistance of 27.59 tons.

It was shown in one of the above tables, that Bessemer metal specimens of the same width, gave a resistance of about 25.38 tons. Other specimens of the same Bessemer plate 2.34 in. wide, gave 25.44 tons with a punched hole, and 32.52 tons with a drilled one.

From these figures, on a width 2.34 in., the apparent loss of tenacity is then 21 per cent. for Martin metal and 22 per cent. for Bessemer metal; it may be assumed that they are sensibly the same.

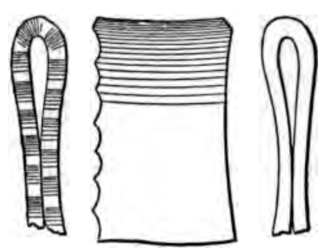
By cutting away in the lathe, the ring surrounding holes

punched in Martin plate, and trying to distort these rings, the metal was found about as brittle as the Bessemer rings.



30.—Bessemer (tempered).

Tempering has a somewhat remarkable influence, when applied to punched steels. It was first observed on strips cut, like the preceding ones, from Terre-Noire and Creusot plates. One edge was punched and the other sheared. These strips heated to cherry-red, tempered in cold water and submitted to tests for deformation showed their first



31.—Martin (tempered).

cracks when they had reached the average form fig. 30 for Bessemer plate, and fig, 31 for Martin plate.

The cracks occurred in the center as often as on the punched and sheared edges. If we compare these deformations

with those obtained after tempering, on planed strips of the same steel, represented by figs. 6 and 7, very slight differences are observable between classes of the same plate.

Tests, after tempering, were also made on 2.34 in. strips cut out of Bessemer and Martin plates having in their center a 0.66 in. hole, sometimes drilled, sometimes punched. These strips broken in the testing machine evinced resistance averaging as follows:—

TABLE I.

	RESISTANCE TO RUPTURE PER SQUARE INCH.	
	Bessemer.	Martin.
	tons.	tons.
Drilled hole......................	44.54	34.46
Punched "	43.27	33.39

It may be then assumed that tempering sheared and punched steels to the same degree, brings them back to the same state as if their edges had been planed and their holes drilled.

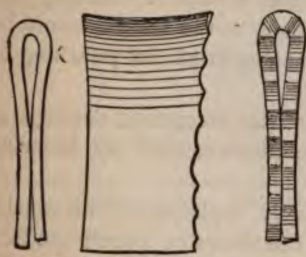
Judging from the experiment of annealing made on rings surrounding punched holes, annealing must produce a great improvement on the apparent resistance of punched plates. This result, pointed out by several authors was verified with Bessemer steel specimens 1.95 in. wide. These, after annealing gave the following average resistances.

TABLE XII.

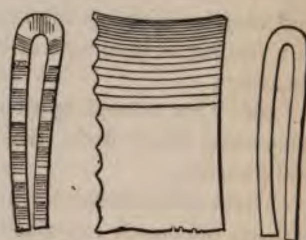
	RESISTANCE PER SQUARE INCH.
	tons.
Punched and annealed....................	29.50
Drilled "	30.01
Punched, enlarged and annealed...........	30.32

Specimens from the same plate, punched without annealing, gave a resistance of 24.49 tons. Annealing then, brings back the steel to the same state as if it had been drilled and planed instead of being punched.

Strips of Bessemer and Martin plate were also cut out with the shears and punched and successively submitted to



32.—Bessemer (tempered and annealed).



33.—Martin (tempered and annealed).

tempering and annealing. By trying to bend them after the operation, they were brought to the forms fig. 32 for Bessemer plate and fig. 33 for Martin plate.

Strips of both kinds, some with punched holes, others with drilled holes, having been submitted to this double operation of tempering and annealing gave the following results.

TABLE XIII.

	RESISTANCE PER SQUARE INCH.	
	Bessemer.	Martin.
	tons.	tons.
Drilled hole	30.13	26.33
Punched "	35.53	30.32

It is probable that the annealing of these last specimens did not take place at a sufficiently high heat to cause the disappearance of all the tempering obtained in the first operation.

By summing up the preceding pages, we may conclude

from these experiments made with plates from 0. 27 to 0.46, inches thick:—

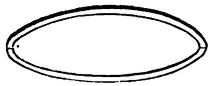
1st. That the effects of punching and shearing are essentially local and spread only over a very restricted region, less than 0.039 in. on the edges of the sheared or punched parts.

2d. That no cracks exist in this altered region;

3d. That tempering destroys the effects of shearing and punching by bringing the metal back to the state it would be in if drilling or planing had been substituted for punching or shearing:

4th. That annealing alone or after tempering destroys as tempering alone does, the alterations caused by shearing and punching.

These different results are easily explained by the considerations previously explained. The shears or punch produce in the neighborhood of the parts submitted to their action a very intense local pressure. On one hand the limit of elasticity in the metal is exceeded; it cannot then bear the same stretching, but this effect alone does not explain the observed increase in hardness and tenacity. On the other hand this pressure causes a solution of the mechanically mixed carbon and effects a real tempering in the parts touched by the shears around the punch holes and on the circumference of the punchings. These affected parts acquire more hardness and tenacity, and are capable of slight stretching only. Tempering thus obtained is much more intense than that obtained by rapid cooling. In reality the pressure of the punch is sufficient to exceed the limit of resistance of the metal and this effect can never be produced by tempering soft steels by simple cooling; in the latter case the pressure and the effects produced by it are necessarily less. Thus a ring surrounding a drilled hole and tempered by the most rapid cooling obtainable gave the deformation fig 34, very different from that obtained with rings surrounding punched holes in the same plates.



34.—Bessemer, drilled tempered.

By admitting this theory, we can account for the different facts observed, and first the influence of the width of the specimens on their tenacity, as shown in Table VII.

Let us suppose the region of action of the punch to be limited to a cylinder the radius of which would be 0.039 in. larger than that of this punch. The different fibres of a test-bar will stretch until the central part tempered and near the hole, stretching less, and consequently bearing the main part of the charge, will break in a crack 0.039 long. From this moment, all the fibres, working equally, should show the normal tenacity of steel plates provided the crack had no great tendency to spread. This effect was produced in the narrow bands, 1.24 in. wide; they were held at their extremities by a bolt running through the holes AA′ BB′ and about 1.17 in. diam. (fig. 35). The effort of tension tended to a transmission following the tangents AB A′B′ at the edges of the two holes, and the fibres were more strained as they neared these lines. It was then at the edges that the maximum stretching was to take place; the cracks could show themselves only under a pretty heavy effort, and had very little tendency to spread. The crack once produced on the whole extent of the altered region, the working section of a band with cylindrical punching (0.66 in. punch, 0.70 die) will be 0.1401, sq. in. Admitting 31.30 tons to be

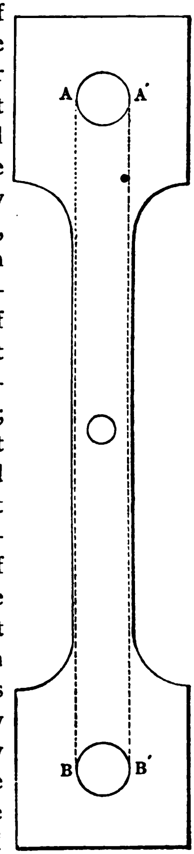
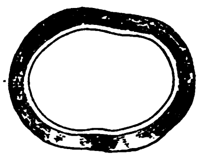


Fig. 35.

the nominal resistance of Bessemer plates, these bands will break under a load of 9827 lbs. which will give as an apparent resistance, 27.85 tons per sq. inch: that is to say, the result observed in Table VII.



36.—Full Size.

In the conical punched hole, the metal is a little less altered than by the cylindrical punching; rings detached around these holes have been deformed only slightly, it is true, but yet quite perceptibly (fig. 36). This result is explained by the weaker tempering produced by this mode of punching; it is well known that, in this case, it takes a less effort to open a hole in a plate than for cylindrical punching, and in fact, under the action of the punch, in the first case the metal is submitted to flexure as well as to the shearing proper as effected by cylindrical punching. In the trial strips stretching is a little more regular; the cracks do not show themselves as quickly, and the final resistance per sq. in. differs but little from that of the drilled strips.

In order to properly show the influence of the position of the punched hole with regard to the tangents AB A′B′ strips 1.24 in. wide were cut out of a Bessemer plate according to the pattern fig. 37; some had drilled holes, others conical punched holes; and the last ones a cylindrical punched hole. The centre of the hole was in every case on the line A′B′ and the altered region was then the one subjected to the greater stress. These specimens gave the following results :—

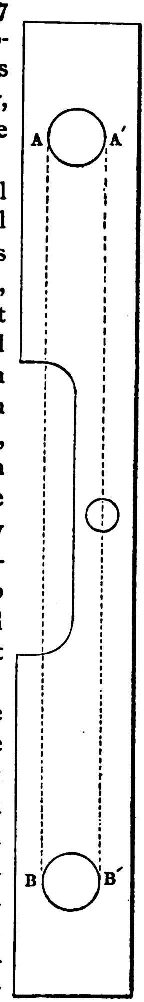


Fig. 37.

TABLE XIV.

	RESISTANCE PER SQUARE INCH.
	tons.
Drilled holes	29.06
Cylindrical punched holes	15.98
Conical " "	21.58

These results should not be compared with those previously obtained; because tension in this case, is complicated by flexure; however, this experiment shows very well the influence of the altered region in a specimen of this kind; it shows also that conical punching has a considerable effect on small strips, although less harmful than cylindrical punching; and that the mode of suspension of the test plates alone, has prevented many experimentors from noticing it.

The decrease in tenacity after punching, which seems more considerable in very wide plates is easily explained. In this case, the outside fibres furthest from the punched hole are the least loaded; in the neighborhood of this hole the greatest tension occurs and at a certain moment the cracks produced in the altered region spread till final rupture. It will be also understood why in two strips both wide, but of unequal width only a small difference is found between their resistance to rupture per sq. inch on account of the cracks spreading when the loads on the central parts are the same.

For strips of average width, intermediate results must also be observed; the difference between the two modes of punching becoming less and less when the width of the specimens is increased.

Where none of these incipient cracks are produced, specimens whether drilled or punched and reamed, can bear a

much greater load per square in. whatever their width may be; they should resist the less per sq in. as they grow wider; experience seems to prove this.

When making tensile tests, the mode of fixing the specimens, and their width, must be taken into careful consideration, in order to secure comparable results.

In practice, when plate-joints riveted more or less close, are to be frequently submitted to extension and compression, the punched plates will suffer a decrease of resistance in the same degree as the large strips in the preceding trials, for the most considerable stresses will always occur in the regions surrounding each rivet.

It is to be supposed that the phenomena stated above, occur whenever any metal is punched, but to a degree depending upon the manner in which it behaves under the punch. The greater or less enlargement of the hole by drilling will be sufficient to remove the cause of alteration. It was determined to prove this with reference to iron plates, and in order to do so, an experiment was made to determine the influence of the widths of the specimens on their resistance to rupture.

TABLE XV.

	WIDTH OF SPECIMEN.	RESISTANCE TO RUPTURE PER SQUARE INCH.
	in.	tons.
Without punching	0.78	17.82
	0.87	17.64
Conical punched hole—0.66 inch punch and 0.81 inch die	1.24	16.81
	1.95	16.69
	2.62	15.10
	3.35	14.72
	4.05	14.79

A second experiment was made to determine whether an enlargement by drilling, of a punched hole, was sufficient to restore to the metal its apparent previous tenacity; the specimens were 2.34 in. wide—

TABLE XVI.

		RESISTANCE PER SQUARE INCH.
	in.	tons.
Drilled hole	0.74	16.94
Punched "	0.74	14.85
" " 0.66 inch enlarged to	0.74	15.86
" " 0.58 " "	0.74	17.20

From these few figures we observe that punching has on *iron* plates an effect similar to that it has on *steel* plates; the extent of the altered region seems a little larger; the apparent loss would be, judging from this last table, about 12 per cent.

Rings cut out around holes punched in iron plates withstood bending like the steel rings previously mentioned; while rings cut around drilled holes were capable, before breaking, of considerable deformation; those from punched holes were broken before their figure had been notably changed. These last rings annealed to cherry-red were bent like those surrounding drilled holes.

These effects in steel can be explained by a permanent alteration of the elasticity in the parts close to the punched hole, and also by a solution in the iron, under the influence of pressure, of foreign matters, and especially carbon, traces of which it always contains.

It has been observed that punched and sheared specimens when brought under the action of tempering, lose the harmful effects of the punch or shears, and behave like drilled and planed plates subjected to tempering. This fact is explained by considerations like the preceding ones. The shears and punch tempering the metal around the points where they act, the specimens so altered have no longer their previous homogeneity, and under a relatively slight deformation incipient breaking shows itself; the test pieces cut with the shears and punch always crack on the edges, the central part never showing any trace of alteration. When, on the contrary, these locally altered specimens are heated and tempered, the parts

previously tempered by the shears and punch are brought back by a high temperature to the same state as the centre; the same quantity of carbon is dissolved at every point; the lost elasticity is restored, and finally, homogeneity is preserved, just as if the specimen had been cut in a planer or by drilled holes and then tempered. Cracks then show themselves in the centre as well as on the edge. In the test pieces subjected to tension the same fact is repeated; specimens punched and tempered bear the same load as the drilled and tempered ones.

It is, as we may perceive, the action of heat, and not that of tempering, which re-establishes homogeneity; thus annealing gives the same results.

In consequence of the facts just enumerated, in order to maintain in steel plates and bars their entire value, shearing and punching should be avoided unless the parts are subsequently annealed or unless the region altered by the action of the tools is cut out. Laying aside, for the present, the propriety of annealing, which we will subsequently consider, it will be seen that sheared and punched edges must be planed or chiselled, and the making of holes must be effected directly by drilling or by punching and subsequent enlargement of the hole by reaming or boring.

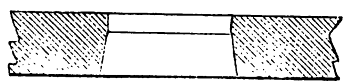
Sheared plates can be easily planed when their outline is straight or nearly so. Otherwise they must be chiselled; this is often done on iron plates when they must be put together carefully and caulked; in many cases it would not require any extra work. Angle iron should be treated in the same manner; but, this operation can frequently be dispensed with, as the end of the bar brought under the shears has but little to do as far as resistance is concerned.

There are difficulties about punching long since recognized; the main one being the mistakes made in the position of the holes. With careful and practiced workmen, this embarrassment is greatly decreased.

In the work done in building ships at L'Orient, where a special effort was made to avoid them, a very small number of holes had to be corrected, hardly 1 in 50. This correcting was done with a rat-tail file or with a gouge, instead of the customary drift, which has for steel plates, the same damaging effects as hammering; these effects will be subsequently shown.

Punching also slightly deforms the plate in the neighborhood of the hole; the greater portion of the bulged part is removed when the hole is enlarged with a drill, and, in any case, a slight hammering, or better still, a few passes on a planer are sufficient to straighten the edges of the holes.

With thin rolled bars, the deformation caused by punching is more important, and making holes in any other way than drilling has been given up. When such plates are very thick, deformation is slight. It has been ascertained on I beams the webs of which were punched, that after the holes were reamed no trace of bulging appeared on the edges of the holes.



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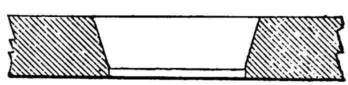


39.—Full Size.

On account of these chief defects of punching which can be diminished but not wholly suppressed, drilling, which has none of them, must be substituted, when it can be done economically, and the available tools will allow it.

In order to arrive at an exact determination of the work necessary to bore holes in steel plates with or without punching, 10 plates 0.31 in. thick, and of great dimensions (each one weighing 600 lbs. about) were taken. These plates, symmetrical and in pairs, were to have the same number of holes; one series of 5 plates was drilled, the other series was punched and the holes enlarged; fig. 38 represents the punched holes

and fig. 39 the holes enlarged with a drill. The following results were obtained:—

TABLE XVII.

DRILLED PLATES.

NUMBER OF PLATES.	NUMBER OF HOLES.	NUMBER OF WORKING HOURS. Machine.	Workman.	OBSERVATIONS.
		hours.	hours.	
1	296	18.30	18.30	Holes near together. Curvilinear outline.
2	226	15.30	15.30	
3	110	9.0	9.0	Holes far apart. Rectangular plates.
4	152	11.30	11.30	Holes near together. Rectangular plates.
5	131	11.0	11.0	
Total..	915			

TABLE XVIII.

PUNCHED PLATES AND ENLARGED HOLES.

NUMBER OF THE PLATES.	NUMBER OF WORKING HOURS OF MACHINES.			NUMBER OF WORKING HOURS—ONE WORKMAN.		
	Punch.	Drill.	Total.	Punching.	Reaming.	Total.
	hours.	hours.	hours.	hours.	hours.	hours.
1	2.0	7.0	9.0	8.0	7.0	15.0
2	1.15	6.15	7.30	5.0	6.15	11.15
3	1.0	7.0	8.0	4.0	7.0	11.0
4	2.0	4.30	6.30	8.0	4.30	12.30
5	2.0	4.30	6.30	8.0	4.30	12.30
Total...	8.15	29.15	37.30	33.0	29.15	62.15

The working expenses were then 65 hours 30 m. for drilling, and 62 h. 15 m. for punching and reaming, which gives an advantage of about 5 per cent. to this last operation. It must be observed that the working expenses for punching comprise the labor of a journeyman attending the punch,

and three laborers handling the plates. These laborers' wages are less than the journeyman's, consequently, 5 per cent. economy is a minimum. The working hours of the machines were, for complete drilling 63 h. 30 m. and for punching and reaming 37 h. 30 m. or 42 per cent. less in the latter case. Finally, the working hours of the drilling machine were 63 h. 30 m. in the first case, and 29 h. 15 m. in the second—in other words, with the same number of drilling machines it is possible, by punching and then reaming, to bore within the same time, 53. 5 per cent. more plates than by direct drilling.

This comparison is made, taking the existing stock of tools as a basis, that is to say, the tools now standing in the iron shipyard at L'Orient. It is probable that reaming after punching could be done much more rapidly with special machinery. On the other hand, it is certain that, if several plates were to be bored, in which the position of the holes was identical, and could be bored all at once, the conditions would not be the same; this would be true in case of plates in which the holes were in a straight line, and the same distance apart, so that several drills in the same machine could be operated at one time. Leaving aside; then, the question of economy realized by the use of multiple drilling machines the advantages of which will often be great, it will be seen that punching holes in steel plates and afterwards enlarging them with a drill, is not disadvantageous as far as cost is concerned, and also that it accomplishes the same results as if the number of drilling machines was doubled.

The number of these machines was rather restricted at L'Orient, when steel constructions were undertaken; the results pointed out above have been judged amply sufficient to cause punching followed by reaming to be adopted, despite the known inconveniences of punching—*i. e.*, lack of precision and deformation of the plates.

The Creusot works have lately put in our hands, to pursue these experiments, pieces of very soft steel plates belong-

ing to the categories B. 10 and C. 11 of their general classification table.

Two specimens 0.78 in. wide of category B.10 gave a mean resistance to rupture of 28.05 tons per inch, and a corresponding stretching of 23.5 per cent. Two specimens of the same plate, punched with a 0.66 in. cylindrical hole and being 2.34 in. wide gave an average resistance of 20.31 tons per square inch.

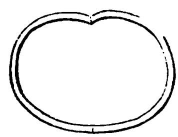
One experiment was made with the plate C.11 in its natural state and one after punching. A strip 0.78 in. wide gave a resistance to rupture of 25.25 tons per in. and 28 per cent. elongation. A strip 2.34 in. wide with a 0.66 in. cylindrical punched hole gave an apparent resistance of 18.46 tons per inch.

It must be observed that the stretching observed in these last experiments is notably inferior to that indicated in the classification table. This difference may result from the mode of fixing the specimens in the apparatus measuring the stretching, or the manner in which the successive operations were made. We will mention again that the tractive force was increased by adding 44 lbs. at a time, and an interval was allowed for each supplementary weight to produce its proper effect. At Creusot the experiments might have been conducted still more carefully and slowly. It must also be noticed that the bars experimented upon at Creusot were not as long as those we broke; stretching was observed on an original length of 0.39 in. while at L'Orient we measured it on an 0.78 inch length. Now, in the period of tension preceding rupture, the specimens have a narrowed section at one point; thenceforth this portion undergoes great stretching, which contributes largely to making up the total stretching observed which is greater as the specimens are shorter.

Whatever may be the cause of the differences between the Creusot and L'Orient observations, it must be noticed that the experiments we made were performed under the same

conditions, with the same apparatus, and are consequently comparable between themselves.

Rings cut out around holes punched in these sample plates cracked when they were brought to the form fig. 40 for plate B 10, and fig. 41 for plate C 11. Rings surrounding drilled holes were completely flattened; they cracked upon trying to open them again, when they reach form fig. 42 for plates B 10



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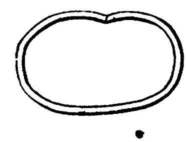

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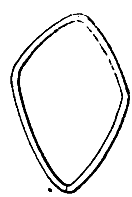

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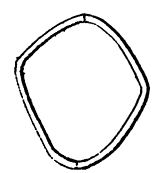

43.—Full Size.

and fig. 43 for plate C 11. The punched hole-rings annealed to cherry-red and cut according to a generatrix were developed so as to bring in to extension the part which had undergone the action of the punch. We were able to flatten them completely without any cracks. From these last experiments it will be seen that these plates are softer than those previously experimented upon.

These last trials are too few to be considered as important as the preceding ones. It will be seen, however, that these plates were much altered by the punch, and that they must be considered, in reference to the action of this tool, like the less soft plates used in the constructions at L'Orient. This

fact could be foreseen from the alteration produced by punching in iron plates previously mentioned.

These Creusot plates, capable, before breaking, of an enormous stretching, are not greatly modified by tempering, as may be seen by the figures quoted in the classification table of these Works. Thus, in admitting the results there indicated, the plates C 11 in the natural state break under a stress of 24.92 tons per inch and have an elongation of 35 per cent. The same plates tempered in oil bear 29.16 tons, and still stretch 33 per cent. Thus, simple tempering slightly modifies the properties of these plates; the punch on the contrary, which strongly reduces the tenacity, modifies them largely. This difference can easily be accounted for.

When plates are rapidly cooled, the external layer, as explained in the preceding chapters, must stretch at the expense of elasticity. The stretching of the plates on the list C 11, reaching their elastic limit under a load of 15.48 tons is at this load very perceptible. We may suppose that cooled exterior fibres will have, under a tension slightly higher than that of the elastic limit, a sufficient volume to contain the metal inside. This inside metal seems then not to be subjected by ordinary tempering to a stress superior to 16.50 to 17.14 tons. The more carburized plates reach their limit of elasticity only under a heavier load; with the same tension, their elastic limit and permanent stretching are less than in the preceding plates. The same tempering must cause a greater pressure and consequently a greater solution of carbon. A slight variation in the amount of carbon which greatly changes the conditions of elasticity, can then produce, by tempering, a very marked difference. The way in which carburized irons behave at the same degree of tempering, depends, as we may observe, only upon the stretching they are capable of.

In the different plates subjected to shearing and punching, the alterations were about as important. In both cases, the metal undergoes, whatever its stretching may be, a pressure

sufficient to reach the limit of resistances to rupture. If we take as terms of comparison, the resistances to tension instead of resistances to shearing, which have been little studied, the plates C 11 are subjected by punching to a stress of 25.38 tons per sq. inch, while more carburized plates such as those used in our works undergo a stress of 28.56 tons ; the difference is slight, and as long as there is not saturation in the solution of the carbon in the iron, the supplementary solutions produced by punching should be nearly as important. The alteration produced by punching in carburized irons depends essentially on the resistance of these irons to shearing.

Plates and rolled beams must often undergo a more or less severe hammering either to straighten them or to bring them to the desired form. The blow of the hammer producing a pressure in the region of impact, we can conceive that its action ought to cause effects comparable to those of the shears or punch ; the resulting alteration should be less important since the pressure produced is not generally strong enough to exceed the resistance to rupture.

To demonstrate the influence of hammering, pieces were cut from Creusot angles and subjected to a vigorous, cold hammering on the whole surface ; under this influence the stretching of the metal was about 7.5 per cent. The bars were then dressed, brought to a uniform section and broken in the testing machine. In operating on six bars 2.34 inch.wide and treated in this manner, an average resistance to rupture of 34.10 tons and a corresponding elongation of 9.7 per cent. were obtained. Thus, hammering had considerably increased resistance to rupture. We observed that the mean resistance of the Creusot angles in the natural state was 29.10 tons per sq. inch. As to the stretching, a notable portion of it, 7.5 per cent. had been evidently absorbed by hammering. In the bars showing 9.7 per cent. stretching, the total was 17.2 per cent. instead of 24.5. The elasticity of the metal had therefore been very much modified by hammering. Finally, we ascer-

tained by filing these bars that they were much harder to cut than when in the natural state; their hardness had therefore been increased. These are the characteristics of tempering. Hammering, as was to be supposed from the received theory, acts like punching, but with less intensity. Under the influence of the pressure which the hammered parts received, the carbon which was found in a state of mixture must be more or less in solution at all these points.

This experiment on hammered bars was repeated with the above mentioned Creusot plates B 10 and C 11. We were able to make only one strip 0.78 in. wide from each plate. For the first, a resistance of 31.73 tons and an elongation of 6 per cent. were obtained; for the second, a resistance of 29.94 tons and an elongation of 10 per cent. From these experiments, although few in number, it is probable that in spite of their lesser carburization these plates received from hammering an effect of the same character as that the plates received which were used in the constructions at L'Orient. We endeavored to do the hammering under the same conditions as in the preceding experiments, but it is very difficult to regulate the intensity of the blows, and it is presumable that these last strips received a more energetic hammering then the first ones.

If it were possible to temper steels to a degree sufficient to produce the solution of all the carbon they contain, they could be subjected to a general and regular hammering without evincing any sensible variation in their tenacity. They would only lose a portion of their stretching properties, corresponding to the part absorbed under the blows of the hammer.

As another consequence of the theories expounded above, hammered bars subjected to annealing should recover, from this cause alone, their original tenacity and elasticity. Bars treated under these conditions, that is to say, hammered on their whole surface and then heated to cherry-red and cooled *slowly, have in fact* given an average resistance to rupture of

29.94 tons and an elongation of 23 per cent. They had therefore completely returned to their previous state.

In the foregoing experiments, the bars were hammered as regularly as possible on their whole surface; the result was a metal obviously homogeneous and about equally tempered. In practice, plates and rolled beams undergo this hammering on a few points of their surface only. After local blows of the hammer, the metal must show indications of defects in homogeneity similar to those observed after punching, that is to say an apparent reduction of tenacity. This experiment is difficult to perform on small bars, for this diminution of tenacity must be considerable in order to be perceptible in breaking; the metal delivered by the Works, although in most cases remarkably homogeneous, shows on several points, slight differences of resistance, but of the same character as that which would be observed after the blows of a hammer.

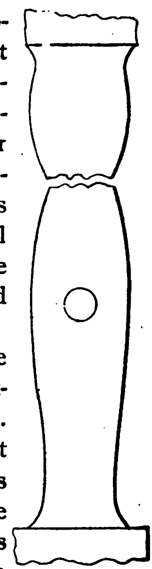

Fig. 44.

We were able to ascertain approximately, the effect of local hammering by the following experiment: strips of Terre-Noire plate, 0.46 in. wide, were subjected to the pressure of a short punch 0.74 in. in diameter; this pressure was produced by a hydraulic press, by placing the specimens on an iron bearing. The punch was impressed into the plates, which after the operation had a depression 0.39 in. deep at the compressed point, but no hole was completely taken out. The specimens were then dressed on their whole surface, and subjected to breaking by tension. Fig. 44 represents the average form of the bars after rupture, and the dotted circumference indicates the compressed part. It will be seen from this figure that the region comprising it did not suffer the same deformation as the rest of the specimens. The breaking stress

per sq. inch was about 31.73 tons. As rupture took place outside of the compressed part, the average resistance of the Terre-Noire plates was naturally to be expected. The average elongation was 18 per cent., a little less than the average elongation found in plates in the natural state. In this experiment, the compressed part had extent enough to bear the whole stress in spite of the more considerable elongation of the external fibres ; but it is evident that in wider strips this region should have broken first, showing the phenomena noticed in punched plates.

The same experiment was repeated ; but in order to lessen the importance of the altered part a 0.58 in. hole was drilled in the centre of the compressed part. The bars thus obtained were in a condition similar to those with punched holes ; only, the steel was less altered at the edges of the hole in the former than the latter, for the pressure it had been subjected to was inferior to that necessary to produce rupture. These specimens broken by tension, showed a reduction in resistance of about 0.58 ton per sq. in.

In another similar experiment, we wished to prove the pernicious influence that a rivet heading tool may have when used on too short rivets.

Strips 2.34 in. wide, drilled with a 0.70 in. drill, received a countersunk rivet, the end of which was vigorously hammered so as to visibly print the end of the tool in the metal. The rivet being removed and the specimen broken in the testing-machine, the resistance was found to be from 0.58 to 1.18 tons inferior to that of the specimens in the natural state.

This pressure may be compared to that resulting from the blow of a hammer ; we can thence know what takes place in a plate struck in one particular point. There is at first, on the point of impact, a crushing of the metal and compression in every direction by the reaction of the surrounding parts. Then, tempering will take place on account of this very pressure. *If, afterwards, this* plate is subjected to a sufficient tensile

strain, a notable elongation will take place in the unaltered part, before any effect of the kind will be noticed in the altered region ; first because the latter has already undergone a certain stretching and was at the beginning of the experiment compressed by the external fibres; also because, being tempered, it is able to bear a heavy load before reaching its elastic limit. But the unaltered part stretching more rapidly, the point of impact has to bear a greater portion of the stress than it would have done in a homogeneous specimen, and rupture will take place at this point with a less effort than might be expected.

When the blow of the hammer is slight, the tempering thus produced is insignificant and without depth; the same effect takes place when a large surface is struck. When hammering steel plates or steel angles cannot be avoided, it will be better to strike on a broad surface which will distribute over a large area the pressure due to the blow.

Plates or angles subjected to local hammering and then annealed, no longer show the defects pointed out above ; the cherry-red temperature to which they are heated restores to the metal its lost elasticity, and slow cooling allows the carbon in solution to separate regularly, so that finally a homogeneous metal is obtained.

The defects in homogeneity, which are consequent upon hammering, must aiso produce in steel plates, a wear sometimes rather rapid on account of galvanic currents developed by it. When studying, in practice, the way in which steel behaves, as to duration as well as resistance, it is most important to get every information concerning the wear, before making observations on the modes of working.

CHAPTER IV.

ON PROCESSES SPECIAL TO PLATES.

INDEPENDENTLY of the processes just described, steel plates to be brought to their final form, must undergo different operations of straightening, planing, and forming, either cold or hot.

Straightening may be done by the hammer or by a machine. In the first case, the metal is subjected to all the injurious effects of hammering; this mode of operation must, as much as possible, be avoided unless the parts are annealed afterwards. In the second case, the straightening is done in a machine — a sort of roll train — made essentially of three cylindrical rolls between which the plate passes, and is thus forced to take a regular curve; a second pass in an opposite direction removes the curve produced by the first. These two operations sufficiently repeated, cause local corrugations to disappear. The piece being subjected in this operation only to a slight and regular deformation and to a general pressure which maintains the fibres in the same state, can receive none of the injurious results of local tempering.

This machine may also be used in curving plates in their wide direction. If the distance between housings allows it, the plate may be put through crosswise; or the cylindrical rolls may be replaced by swelling ones, the pressure of which, extending over the whole surface, cannot do any damage.

This process of straightening has been adopted almost exclusively for the plates used at L'Orient; it was ascertained that after the operation they were as soft as before.

With plates which cannot be brought to the desired form by this machine, it will be necessary to produce the deformation through a regular pressure distributed over a certain surface. If the operation is done cautiously, the metal will remain about as soft as before; the deformation will only absorb a part of the elongation it is capable of before rupture. In most cases it will be unnecessary to anneal.

If it becomes impossible to form the plates without hammering or without intense local pressure, or if the deformation is to be considerable, it is necessary to proceed cautiously and methodically in order to avoid cracks during the operation. The hammering must be done by light blows on the largest possible surface, the required shape must be completely obtained only after several operations. Finally, the plate being formed, it must be annealed immediately, because plates in an unstable state of equilibrium are more exposed to breaking under external influences in proportion as they remain longer under these conditions.

The heating of Steel plates demands particular caution, and it has been long recognized that they should not be treated like iron plates. For, let us consider what takes place in a plate heated in a forge fire on a region of greater or less extent. While the exterior fibres which are not brought under the influence of the fire preserve the same positions and dimensions, the part heated to a high temperature is expanded and so compresses all the surrounding metal. This compression causes tempering and a permanent deformation in the region surrounding the heated parts. When the plate is withdrawn from the fire, the fibres previously compressed and tempered will be subjected to a progressive tension producing an alteration of elasticity in a direction contrary to the preceding one, and greater and greater as the cooling takes place;

but the effect of tempering resulting from the original pressure will not be decreased by this tension. The heated part, on the contrary, is subjected to compression only when it is in the fire ; it can not be tempered by this alone. In cooling, it is subjected to a stress of elongation only, coming from the resistance the deformed external fibres oppose to its contraction. A plate originally homogeneous is therefore, after going through the fire, in a state very different from its previous one.

When afterwards, it has to be subjected to a slight deformation, its different fibres do not work together ; some go beyond their limit of resistance, and the plate may break under a slight strain. These breaks take place, in some cases from the most insignificant causes ; the concussion of a hammer blow, or of a centre-punch, a decrease in temperature of a few degrees, etc., etc.

It must be noticed that rupture ought to take place in most cases, not in the most heated part, but in the neighboring region which has been tempered, and has had to undergo in this state, while cooling, a permanent elongation; experience, in fact, verifies this.

Local heats must therefore be avoided as much as possible ; but if by this means a plate has been brought to its definitive form without accident, it must be immediately annealed, and in this operation, every effort should tend to gradual heating, because a sudden increase of temperature at a point where molecular tensions were already exaggerated might lead to rupture. When proper care has been exercised in working the plates, these tensions ought to be quite slight ; the plates can then be put suddenly into an annealing furnace at a cherry-red heat. Rupture could occur only if, at the time of putting the plate on the fire it was in a very unstable state of equilibrium. The annealing at L'Orient, was done under these conditions, and it was not found necessary to deviate from this practice. When the plate is heated regularly at a sufficient

temperature, it can be left to cool slowly, and the injurious effects of local heating will be completely destroyed; homogeneity will be re-established.

When it is necessary to bring a steel plate to a high temperature at one point, it may, in order to decrease the risk of rupture, be heated progressively in a charcoal fire, and burning coals may be distributed over a certain surface around the region to be brought to maximum temperature, thus progressively diminishing the heat at successive points away from the hottest point; the endeavor is in other words to bring a certain intermediate surface of the plate to a degree of heat intermediate between the hottest and the coolest parts.

For the reasons mentioned above, all local cooling, which would produce injurious effects similar to those of local heating (although less in degree), must be avoided.

The hammering of hot steel plate does no damage when it is done at a sufficiently high temperature; but, when a plate is subjected to hammering from the moment it is red until it is cold, the effect is at least as injurious as that of cold hammering. The blows struck when it is hot maintain the solution of carbon produced by the high temperature, while cold hammering must produce a solution of the mechanically mixed carbon. It will be understood then, that in the case of a prolonged hammering, from the time the plate is red until it becomes cold, the final solution of carbon is more complete than in the case of cold hammering alone.

Therefore, when a hot plate has to be hammered, this operation must be stopped while the temperature is yet high enough to allow, by subsequent cooling, the separation of the carbon. With this precaution, hot hammering will produce no injurious effects. When steel plates are to be greatly changed in figure, the work may be executed by different processes, never losing sight of the previously indicated precautions. The plate can first be made to approach the desired

form by a deformation while cold, by pressure on a part of the surface or by slight hammering; this should be stopped when breaking might occur from pushing the deformation any further. The plate must then be annealed at a very even cherry-red: it will then be able to bear a new deformation. After this annealing, it will be noticed that the plate is less hard to work than at the end of the former operation. The plate will thus be subjected to a series of cold bendings and anneal-

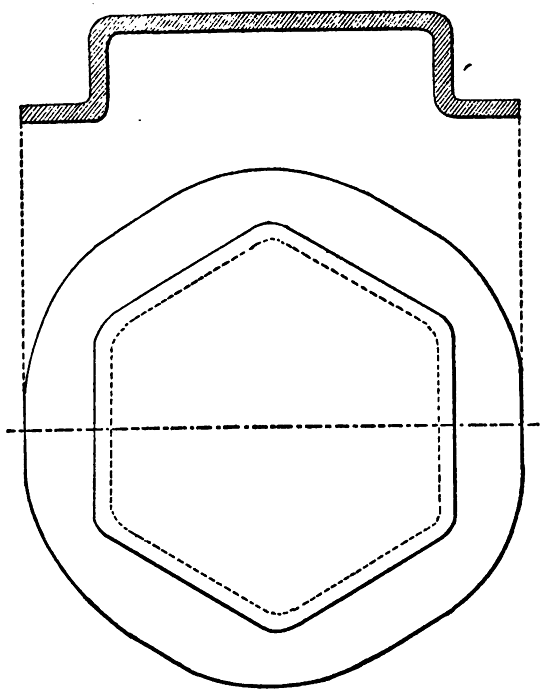

Fig. 45.

ings, until it reaches the desired form. After the last annealing, it should be but slightly bent (avoiding the use of hammer),

merely to remedy the slight change of figure the last heat may have caused.

A plate may also be worked after having been heated over its whole surface; in this case, the form must be reached by pressure on a large surface, by bending, or by a hammering which should cease at dark red. When the piece is brought to its form, by one or several heats, it should be put in the fire for the last time and left to cool slowly, without working.

If this annealing should have produced a slight deformation, it may be remedied by slight pressure when cold.

These two methods are equally sure, when the principles as set forth, are carried out.

As the working of hot steel plates presents no difficulty when stopped at dark red, this metal should be well adapted to stamped work which is done by a few rapid blows. We will mention two examples.

We have been able to obtain without difficulty and in large numbers, the pieces fig. 45, made of steel plate 0.39

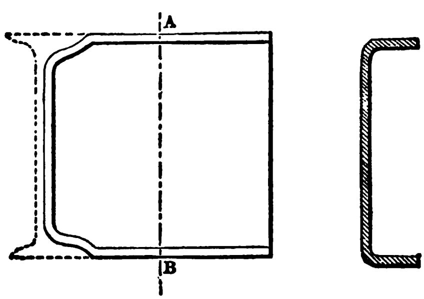

Fig. 46. Section A B.

in. thick. They present, as may be seen, a shape similar to that of a hat the crown of which is polygonal. In making them the anvil carried a prism-shaped die, and a corresponding stamp was fixed to the steam-hammer head. The plate heated to bright cherry-red, was placed on the anvil, and by

two blows of the hammer was brought to the desired form. As this working was all done, on account of the rapidity of the operations, while the specimen was at a high temperature, the plates were found to be very soft after the stamping; the file and chisel cut them as easily as before. Subsequent annealing was dispensed with.*

Other plates were stamped to form filling pieces (fig. 46) † between the I beams making up the framing of the decks. A flange 3.12 in. wide and 0.31 inch thick was turned down on three sides of these plates; these flanges had shoulders corresponding to the flanges of the I beams. The plate, being placed on an anvil, was formed by one blow of the hammer. But it was not possible to give to the flanges a decided enough outline by this operation alone; their angles had to be formed at a second heat, when the plate was worked on a special anvil with a hammer. Complete annealing followed this last manipulation. These pieces were thus manufactured in great numbers without any particular incident; the metal was as soft as in the original state.

The annealing, for steel plates, must be very regular over the whole surface, as they are generally very thin; the temperature should be obviously the same over the whole thickness. This annealing might be effected in a charcoal fire without blast; but a perfect equality of temperature on a sometimes considerable surface is never certain. A better way is to heat them in an ordinary furnace, or still better in a Siemens furnace; the temperature, in the latter, can be very well regulated, and it is easy to avoid a flame either oxydying or carburizing which would have the effect of modifizing the homogeneity of the plate. In order to obtain perfect annealing the heated plate must be afterward cooled slowly. This

* More than 70 caps, fig. 45, were stamped—none were defective.

† "Over 700 pieces like fig. 46, and still more complicated forms were manufactured without spoiling one. We did not succeed in obtaining a single one from fine Guerigny iron plate, excellent in quality."

operation is easy with a charcoal fire, where the plate may be left until it is completely cool, by letting the fire go out; but it would be impossible in a gas furnace. This precaution is, however, not necessary with plates which are not very thick. It is sufficient to cool evenly on the floor of the shop, avoiding local contact with heat-conducting matters and above all with the irregularly damp ground, which would cause at certain points a fall of temperature more rapid than at others. The difference of temperature between the exterior and interior of a plate, in the different phases of its cooling, it so slight that the more rapid contraction of the superficial fibres can exert but a small pressure, and consequently small tempering; besides, complete cooling under these circumstances demands considerable time; the interior and exterior, separated only by a few millimetres, one centimetre (0.39 in) at most, are maintained at very nearly even temperatures. At L'Orient the steel plates were left to cool on cast iron curving plates.

The gas furnace is the most convenient and simple means for bringing altered plates back to a state very near the maximum of softness they are capable of. Punched plates can easily be subjected to annealing under these conditions; the heat they undergo suppresses the injurious effect of the punch, but they have to be made flat afterwards. This operation does not produce any obvious variation in the position and form of the holes; it may, therefore, be used in many cases to obviate the effects of punching, instead of enlarging the holes, as treated of in the preceding chapter.

The precautions demanded in the working up of plates as we have just stated* evidently assume more importance as these plates are richer in carbon, or more steely; but, even with the softest metal, they must not be lost sight of. It is known that, with iron plates vigorously worked and subjected

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* More than 1,653,000 lbs of steel plates were used according to these different processes at L'Orient; no rupture was observed.

to heats and local hammering, care is taken to anneal them, when it is desired to restore to them all their homogeneity and elasticity. They are much less subject than steel to the phenomena of tempering, since they contain only traces of carbon; the elastic properties of the metal are but little varied by local pressures, and such ruptures as appear spontaneous in steel are not to be feared. The main object of annealing is to restore the elasticity absorbed by the deformations, but it nevertheless contributes to the disappearance of the few defects in homogeneity, which may exist in the very constitution of the metal.

CHAPTER V.

ON PROCESSES SPECIAL TO ANGLE-BARS.

ANGLE-BARS, before being brought to their final form, have to undergo successive operations varying with their length, and consisting of opening or closing the flanges, to form acute

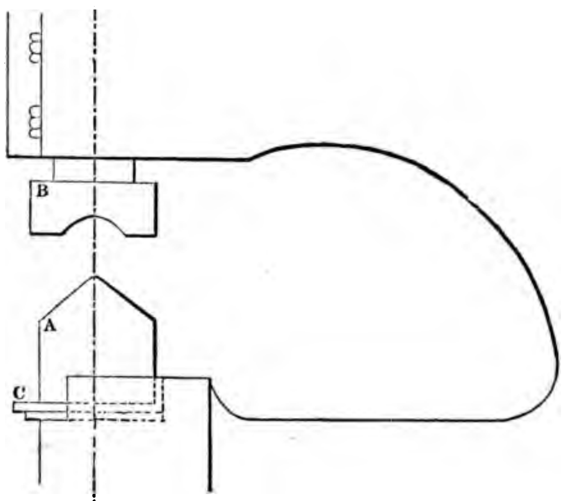


Fig. 47.

or obtuse angles, and also in bending or curving the flanges as formed by the first operation.

In the ships built at L'Orient, when the bending was not

too decided, the work was entirely done cold, and a great part of the angle bars used there were so treated.

Changing the angle of the flanges was done with a heavy punching machine somewhat modified. To open the bars,

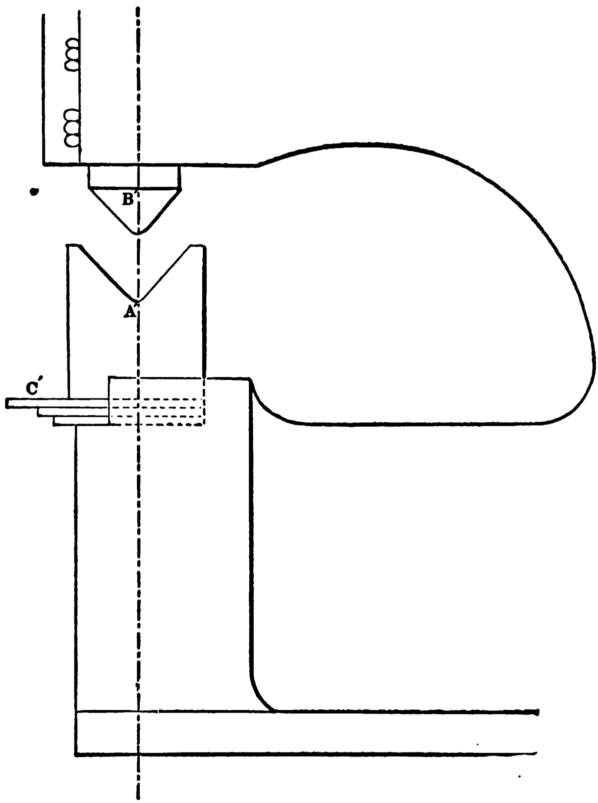


Fig. 48.

that is to say, to produce obtuse angles, the apparatus fig. 47 *was used* The die was replaced by a piece A, the upper out-

line of which formed an obtuse angle; the punch was replaced by the piece B, correspondingto the profile of the piece A. The moveable blocks C allowed varying the height of the piece A with reference to the piece B. The angle-bar was placed on the die A, the punch B pressed on the angle which was the more opened in proportion as the punch reached lower in relation to the die, that is to say, in proportion as the die was raised higher by the blocks C. The smallest effect was obtained by removing all or part of the blocking, which moreover could be made to vary for different parts of the bar. Care was taken, when it was desired to open a certain part considerably,

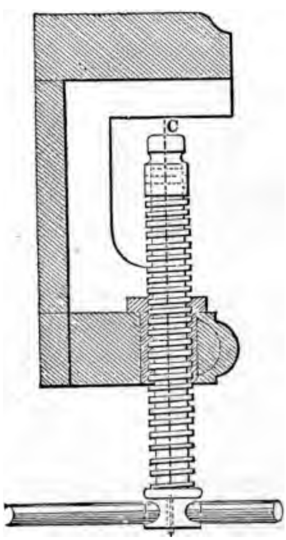


Fig. 49.

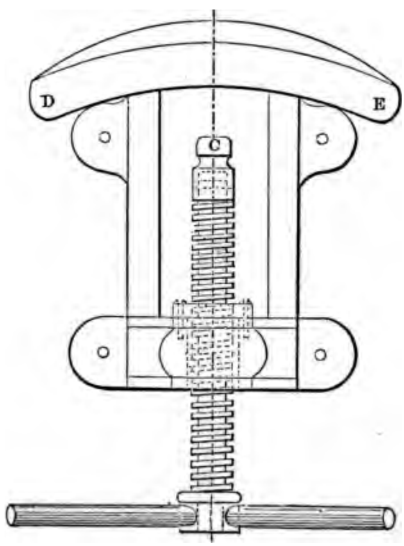


Fig. 50.

not to let the machine exert, at one movement, its maximum effect, but the result was arrived at by a series of deformations on a certain length, corresponding to several successive block-

ings. For the most obtuse angles, the pieces A and B were replaced by others more decidedly obtuse. The angle-bars, after having been put through the first machine, were subjected by another to one or several operations, always varying the blocks C. To close angle irons, that is to say to obtain acute angles, the same punching machine was used but the pieces A and B were replaced by others as A′ and B′ fig. 48. The punch B′ pressing in the angle, forced it into the die A′ the action of which was to close the flanges to an acute angle. The variable blocks C′ allowed as before different degrees of closing the angle, and so arriving at very acute forms by several successive operations. The most acute forms were reached by subjecting the pieces to new deformations by replacing the pieces A′ B by others still more acute.

The angle bars being brought to the proper angle were then taken to the bending machine. This operation was effected by screw presses, fig. 49 and 50. The piece was placed on the fixed points D and E upon iron blocks to prevent an alteration of the angle previously obtained; the end of the screw was furnished with a moveable head C which did not follow the rotary motion of the screw, and in one flange of the iron could be fixed if necessary. The workmen, by manipulating arms fixed to the head of the screw, subjected the piece to a greater or less pressure and brought it to the desired change of shape.

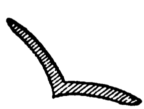
We endeavored to estimate the alterations produced in the metal by these two operations of bending and changing the angle of the flanges. Trial bars were cut in iron curved according to the different radii, some with their angle altered and others not. By operation on angle-irons 2.92″ × 2.92″ × 0.31″ and 3.93″ × 3.12″ × 0.39″ the following results were obtained:

ANGLE.	RADIUS OF CURVE.	STRAIGHT FLANGE.		CURVED FLANGE.	
		Resistance in tons per square inch.	Elongation per yard.	Resistance in tons per square inch.	Elongation per yard.
	feet.		feet.		feet.
0°	9.84	31.22	0.539	30.57	0.567
0°	3.93	27.34	0.539	28.75	0.300
0°	2.68	30.26	0.300	32.04	0.195
13°	9.84	29.19	0.508	28.94	0.552
18°	9.84	30.84	0.463	31.54	0.500

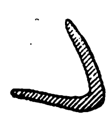
These figures show that curving to a large radius and a slight changing of the angle have but little influence on the elongation and resistance to rupture of test pieces taken from angle bars. With a 9.84 ft. radius and an 18° change of angle, the elongation observed was above fifteen per cent. A great number of angle bars for ribs of the ships built at L'Orient were worked under these conditions without showing any peculiar phenomena; they were however below the limits mentioned of curving and changing the angle.

These operations were rapidly performed and gave very satisfactory results as to precision and economy.

When the angle bars at the extremities of the ships, which required a more decided curvature and change of angle had to be formed, the conditions of this mode of cold working, at first so simple were considerably complicated. The process used in



51.



52.

changing the angle involved the defect of bending the flanges in their width when strong acute or obtuse angles were desired

(fig. 51 and 52). The region around the angle resisted deformation, which then came on the surrounding parts. The flanges which formed obviously plane surfaces after a slight change of angle became concave or convex for very acute or very obtuse angles. These angle bars could not be laid close upon the plates they were to join, and this rounded part had to be dressed off. This might be done, if necessary, for obtuse angles, by chiselling off the external part forming the top of the angle; but, for acute angles, the object could have been reached only by hammering, the injurious results of which have been seen above.

Moreover when bending was done at a rather short radius, the flange of the bar which was to remain flat and which was brought under the action of the screw, was compelled to contract and work under the effect of compression. A series of local protuberances were produced, and as they assumed considerable magnitude it was impossible to remove them by the press alone; it was necessary to resort again to hammering. Under the influence of these various causes,—curving to short radius, decided change of angle, and hammer blows, rupture occurred in a few bars at the beginning of the constructions. These ruptures were generally produced by hammer blows; a few took place while bending after hammering. At this period of the work the extent of injury due to hammering was not known; it was only after these accidents and the experiments mentioned above that we were led to abandon all careless hammering. However a few cases of rupture had taken place in bars which had not suffered from hammer blows; this fact seemed *à priori* rather extrordinary when we considered the elongation obtained in bars cut from bent angle bars the angles of which had been changed. But we were able to account for it by attentive observation of the conditions under which the operations had taken place, conditions which were easily modified as we will explain, so as to make the *cases of rupture* exceedingly rare.

The processes used to bend and to change the angle had in themselves when decided deformations were to be obtained, the defects of hammering by producing local pressures, and as a consequence, local tempering. This fact may be noticed in the operation of opening or closing the angle. The parts which receive the impact of the press-tools which correspond to the die and punch in the punching machine, are compressed very little for small deformations, much more so when the angles become very different from a right angle, but above all when it is desired to obtain by one single operation a heavy change of angle. For in this case the fibres included between the closed or opened region and that surrounding it, which is not yet touched, are obliged to stretch permanently. When afterwards this neighboring part is subjected to deformation the stretched fibres must be compressed so as to be brought into line with the previously worked parts. In order to avoid or at least to greatly modify this effect, the angle bars were submitted to a series of small changes of figure. With this precaution the injurious effect of compressions was considerably decreased and was distributed upon a greater number of points.

Moreover, the deformation of an angle bar with a press

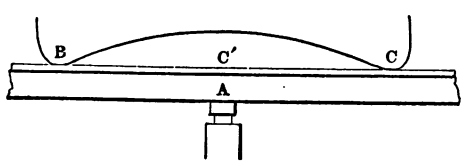


Fig. 53.

requires a greater effort, in proportion as the piece has larger dimensions. This pressure exerts itself in part at the point A (Fig. 53) where the screw works, and in part at the points B and C forming the bearing points for the specimen. There was then at these three points local tempering which did not

take place in the surrounding parts, and which might subsequently be a cause of rupture—a more important cause as the angle bars opposed more resistance. This effect, which we did not think of remedying at the beginning of the work, was notably lessened by interposing between the angle bar and the points A B C, blocks, which distributing the pressure over a considerable surface, much decreased its intensity at each

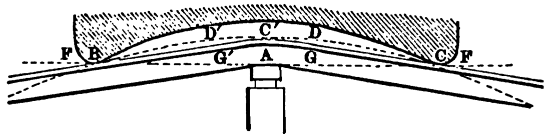


Fig. 54.

point. Before taking this precaution, it was observed that angle bars after having been subjected to a certain degree of deformation began to oppose more resistance—became harder to work than at the beginning of the operation. By employing blocks, this effect became less noticeable.

It must be observed besides, that an angle bar subjected to a pressure at A (fig. 54) will not be deformed on its whole length B C 'C ; elongation will take place mainly in the neighborhood of the point C', between the points DD' for instance. If it is desired to bend the bar to the arc of a circle with a radius of 3 metres, the point C' may be brought to the curve by one blow on a point of this circumference, the points F and F' coming to B and C.

The elongation caused by flexure will be the difference between the curve B D' C' D C and the length F F.' This elongation relatively to the length F F' is slight ; but in fact it is furnished by the length G G' which becomes D D', and this elongation acquires then per metre, considerable value. It is therefore important, in bending with a press, to operate *on points sufficiently* near to each other, so as to produce a

series of partial deformations before arriving at the final form ; too great local elongations should also be avoided.

These precautions, the necessity of which was soon felt, were observed in case of most of the angle-bars, and were sufficient to prevent rupture in pieces that were not hammered.

For angle bars extremely opened or closed, and bent to suit the extremities of the ships, it was indispensable to obviate the causes of weakness just pointed out. With this aim in view several processes were used.

The angle-bars were first subjected to a portion of their total deformation ; then they were annealed in a plate-iron oven heated with wood. The oven and its contents having reached the desired temperature, all the orifices through which air might enter were closed, and the whole was left to cool completely. The angle-bars, after having been thus heated to cherry-red, became malleable again and were easily worked ; this change was much noticed by the men who worked the presses. The pieces could then be subjected without fear to renewed bending and change of angle, which having reached a certain point, were followed by a new annealing, and so on, until the desired form was obtained. Annealing at cherry-red does not deform the angle-bar as much as might be supposed. At this temperature, the metal retains a certain rigidity ; it warps but little under the last heating, and may, by slight bending, be restored to its exact form.

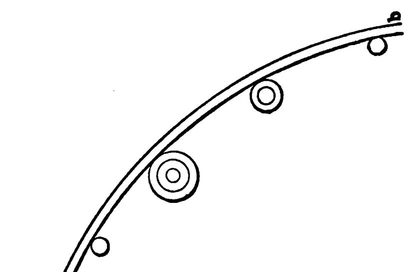
While operations by this method were taking place, a certain number of pretty strong angle irons, $4.68'' \times 4.68'' \times 0.55''$ for instance, were worked by another process, using, forge fires. The blacksmiths intrusted at first with this work, wanted to treat them like ordinary iron, and frequently neglected the recommended precautions ; a few cases of rupture were observed. These men were replaced by carpenters inexperienced in taking care of a fire and disposed to pay the greatest attention to the instructions they received. They

completely succeeded without accident, in bringing the bars to the desired form. These pieces were heated with charcoal in a common forge fire with a tuyere. The fire was bright at the point where the most heat was needed; but, in the angle of the bar, burning coals were distributed, growing fewer as they got further from the point heated the most. The bar was thus heated on a great length, and this heat gradually lost itself either way from the point subjected to the direct action of the forge fire. The angle-bar, brought to the desired temperature, was curved and changed in angle by bending—avoiding hammering, wherever possible. As the operation was done by successive heats, the points which, previously, were indispensably hammered, found themselves at the following heat, in the neighborhood of the hottest point, and were so much heated that, upon cooling, the carbon separated from the solution, as in the other parts of the metal. As a further precaution, after the forge work, the angle-bars were annealed over their whole length in the temporary oven mentioned above.

This last method gave good results; but it was slow and expensive: it was abandoned as soon as a Siemens furnace in the iron ship yard was fired. The-angle bars requiring curving and change of angle, were then shaped on curving plates after a general heating in this furnace. They were, in this case, heated to a cherry-red, and bent with crowbars and levers; they were thus brought in one or two heats to the required form. This form was traced on the plate in the ordinary manner with pins more or less bent according to the opening of the angle. A sheet iron band *a b* bearing on these pins (fig. 55 and 56) gave exactly the outline of the flange nearer to the vertical; the other flange rested on the plate. Care was taken to hammer the angle-bar only when red-hot, and a less temperature was employed only in case of manipulations less liable than hammering to alter its structure. At first the curving was done without using the band *a b*; but the pins left their print on the flange of the iron which bore on them, and there

appeared a series of local projections which the workmen always tried to hammer down when the piece was cold, thus sometimes causing rupture. It was recommended to the workmen to use mainly levers and wooden mallets, and to work the bars when red; however, when deformities were observed at a lower temperature, hammering was admitted by using wide surfaced flatting tools which distributed the blow of the hammer.

After these manipulations, the angle-bars were put for the



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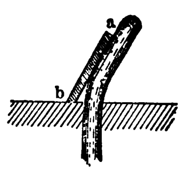


56.

last time into the furnace; this was for annealing, and they were left to cool on the curving plates. Care was taken then not to make them undergo any work, except the slight bringing to shape they might need, and even this was done with wooden mallets. Annealing destroyed the injurious effects of all the hammering. The use of the ordinary hammer was forbidden only to prevent breaking while working; but a bar formed without this precaution, and luckily not broken, would find itself, after annealing, in very good condition.

At a cherry-red, the temperature of annealing, the angle-bars could be taken out of the furnace without losing their form. It was sufficient to sustain them at several tolerably close points and carry them to the curving plates. We hesitated at first about cooling them on a metallic surface—a good conductor of heat—but it was ascertained that cooling took place very slowly; $4.68'' \times 4.68'' \times 0.55''$ bars took about two hours to return to the surrounding temperature. With the small thickness of metal in angle-bars, as in plates, such cooling seems amply sufficient to avoid the effects of tempering; but if they should manifest themselves, there would be no great damage, since they would occur regularly over the whole piece. What must be avoided above all, with reference to subsequent manipulations, is local tempering which puts two neighboring points of the metal in dangerous conditions of resistance.

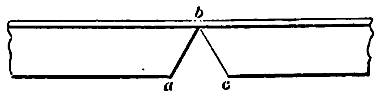
These angle bars, manipulated while hot, were afterwards rapidly brought to their form by presses, and we were able to ascertain, by the effort required for deformation, that the metal was as soft as in the original state.

If the curve of the finished angle bars was too considerable, and the bars too long to be put into the furnace, the annealing was applied in two heats, one at each extremity, taking care, in the second heat, to put in the fire every part that had not been put there before. Sometimes the angle bar was curved so as to go into the furnace whole, and the final curving was done in the press when cold.

This mode of working with the furnace has been more or less modified; often changing the angle was done in the punching machine; but the principle of the method has always been the same.*

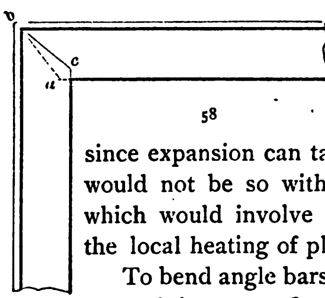
* Towards the close of the ship building at L'Orient, when the workmen were well practiced, 6560 feet of angle-bars were worked cold and 2624 feet hot; 9 bars only were broken, 4 cold and 5 hot; in both cases *the bars were annealed* as a last operation.

Besides these processes of general deformation to which most angle-bars were subjected, a certain number among them had to form shoulders and knees, at right, acute or obtuse



57

angles. The shoulders were formed by heating the required parts in a forge fire; care was taken to hammer the metal only when red hot, and after this operation the bent part was annealed. The heating of angles over a portion of their length is not inconvenient, if the temperature is even on the whole width of the flanges, since expansion can take place without difficulty; it would not be so with the local heating of a flange, which would involve all the defects pointed out for the local heating of plates.



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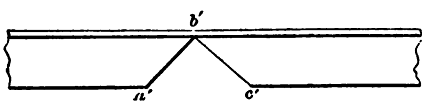
To bend angle bars to forms more or less approaching 90° it was at first tried to operate as with iron angle-bars by cutting out of the flange to be welded a triangle *a*, *b*, *c*, (fig. 57), the lips of which *a*, *b*, and *b*, *c* were thinned out: the bar was bent (fig. 58) so as to bring the two lips together, and these were then subjected to a welding heat. This operation was done with difficulty; on 10 trials, 3 missed, while the others were far from being perfect.

Better results were attained by another method: A tri-



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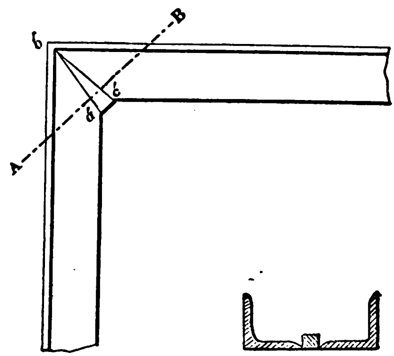
angle *a*, *b*, *c*, was cut out from the bar the angle of which *b'* (fig. 59), was more opened than in the preceding case (fig. 58),

so that after the bending of the flange, the thinned out edges did not touch (figs. 60 and 61). A small piece of wedge-shaped iron was placed between the two lips. The whole, being heated to a sufficient temperature, was hammered; the piece of



60. 61. Section A B.

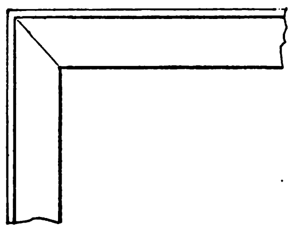
iron was welded to the lips *a′ b′*, *b′ c′*, and a good weld, offering great resistance to the opening of the knee, was obtained.

The bars formed in this manner were annealed, as were all those which had to undergo a forge fire. It must be noticed that the two parts of the bar joined by an iron piece can have only the resistance of iron to rupture, supposing the weld to be as perfect as possible. In order to establish a more complete homogeneity, it would be necessary to subject the angle-bar to a series of annealings, or to a prolonged one; but then the same phenomena observed in any piece of iron subjected to too many heats without drawing out would occur; the fibrous texture would be altered and replaced by a crystalline texture; the steel would approach the state in which it is when it has just been cast.

In the construction of boilers, the knees having almost always more resistance than necessary, the welding of angle-

bars by the interposition of an iron piece will generally furnish a sufficient solidity and the certainty of good calking.

In the construction of ships, angle-bars bent to 90° are



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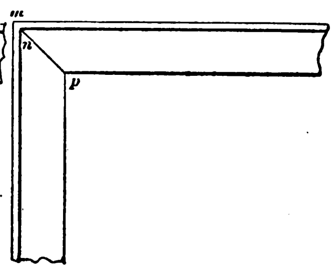

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generally joined by plates the resistance of which would be but little increased by the use of welded angle-bars. Therefore, in case of the bars used at L'Orient, whenever they were not destined for water-tight places, we were content to cut a triangle as for welding and the two edges of the cut were then brought together by bending; the untouched flange preserved thus a great part of its value (fig. 62).

In the case where the angle-bar was to be calked, a 56° triangle was cut out approximately correctly by the angle-iron shears, the two ends were then dressed with a chisel and file; after riveting, the joint *n*, *p* (fig. 63), was carefully calked. Thus a satisfactory result was reached in an evidently economical manner.

If it had been necessary to form a complete frame of angles, the 4 sides should have been carefully fitted in a forge fire, thus necessitating many after-touches.

These processes were used also for obtuse or slightly acute angles; for those the acuteness of which was very decided, welding was resorted to in consequence of the difficulties encountered in calking. It was observed from the difficulties experienced in welding the lips of the bent angles directly,

that the metal furnished by Creusot was not very well adapted to welding under these circumstances; *à fortiori* the Terre-Noire metal should be similar.

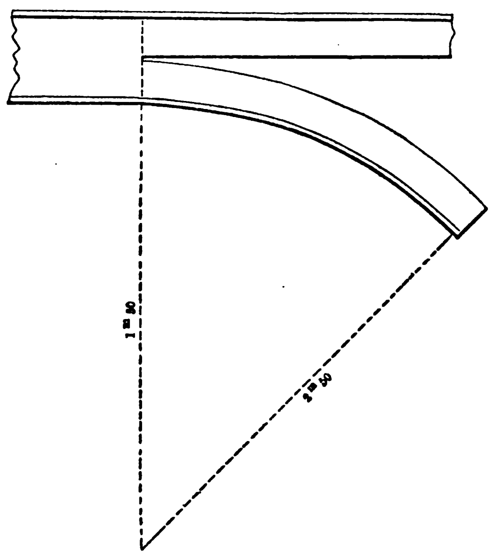
But when welding can be done on a considerable surface it succeeds perfectly. We tried to utilize the cuttings of Terre-Noir plates by making them into piles and rolling them. Small pieces for machinery were thus made, among others a shaft about 3.14″ in diameter, which was very sound, and received a very fine polish. Trial bars made with steel plates piled and rolled together and well annealed, before being broken, gave an average resistance of 27.28 tons per inch, and an average elongation of 25 per cent. Other bars obtained in the same manner, but tempered, gave a resistance of 38.58 tons with 10 per cent. elongation. We were also able by rolling in the same manner steel plate cuttings, to manufacture armor plate bolts 3.14 inch in diameter, which resisted well the shock of cannon balls. These results prove that cast metal welds on a large surface, at least within the limits we have experimented upon.

All the angles worked up according to the principles explained in this chapter, came, as we said before, from Creusot, and belonged to the category of least steely materials employed. Had they been manufactured from Terre-Noire metal, it is probable that more care would have been required during the work, and that none of the indicated precautions should have been neglected.

CHAPTER VI.

ON PROCESSES SPECIAL TO I BEAMS.

THE I beams manufactured by Messrs. Marrel Bros., at Rive-de-Gier, from Terre-Noire steels, received two changes of form: 1st, some of them were employed for deck-beams:



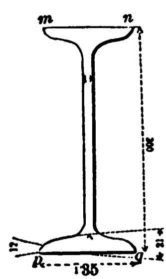
64

each end had to be split, and one of the branches curved on the arc of a circle, to 4.92 feet radius (fig. 64). From the

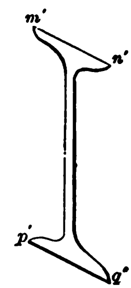
terms of the contract made with Messrs. Marrel, the I beams were to stand the operation while hot, this being the condition of acceptance. 2d. The other beams formed the ribs or frames of the plated parts of the ship; in certain cases they were to be curved, and in others their flanges were to be inclined in relation to the web; thus the original profile *m, n, b, d,* (fig. 65) was to be brought to *m,' n,' b,' d,'* (fig. 66).

For the first set of I bars forming the deck beams, the web was to be split and one of the flanges bent.

The ease with which angles had been worked cold, called attention to the possibility of curving the beams without heating them. In order to obtain the longitudinal slit, a hole



65.



66.

was drilled to limit this slit; then a cut was made by a planer. The beam was then placed on curving plates, where a strong angle-iron A B (fig. 67), forming the arc of the circle the flange was to conform to, had been previously fixed. A strong block C, held the extremity of the split beam. A lever E F, made from a long I beam, fixed at one end and subjected at the other to sufficient tension, furnished the necessary power to effect the deformation; its action was transmitted to the beam by a wooden block placed near the beginning of the cut.

Out of 15 I beams treated under these conditions, 12 stood

the work very well; 3 broke during the latter part of the operation near the beginning of the cut. On all these beams an elongation of about 8 per cent. was observed on the convex side of the web; the flange which was bent showed but an insignificant compression of a few millimeters. It was found, besides, that the elongation of the fibres was obviously more important in the half nearer the beginning of the cut than in the other half.

Trial bars cut out from different parts of the web and

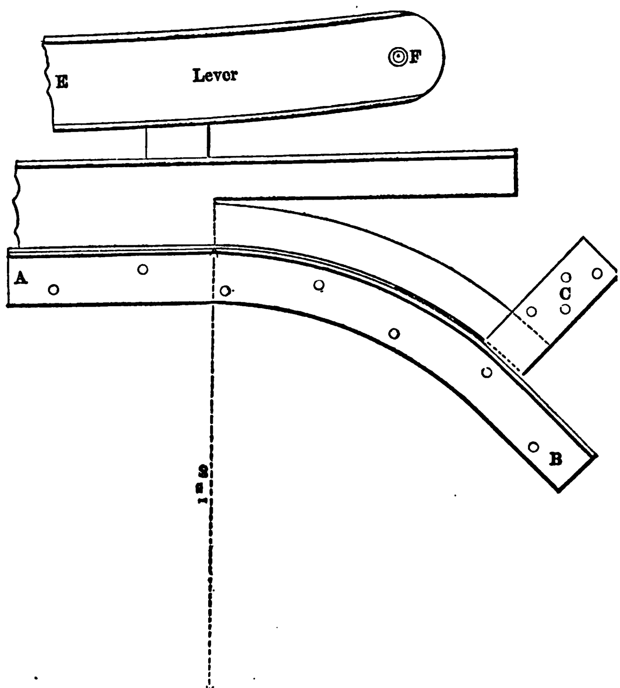


Fig. 67.

flange gave about the same resistance to rupture as the beams in the natural state. The pressure on the compressed flange

was therefore insufficient to produce any appreciable difference; the elongation was still at least 17 per cent. It must be noticed that the test bars could not contain the fibres near the convex edge of the web which had stretched most; they were cut as near to this region as possible and we may conclude with certainty that the fibres of the edge tried alone would have given an average elongation or 14 per cent.

As none of the phenomena due to tempering were produced by this flexure, the fibers retained nearly all their constitutional homogeneity; it is presumable that the ruptures were caused by the increase of work which the parts around the beginning of the cut had to perform during the latter part of the

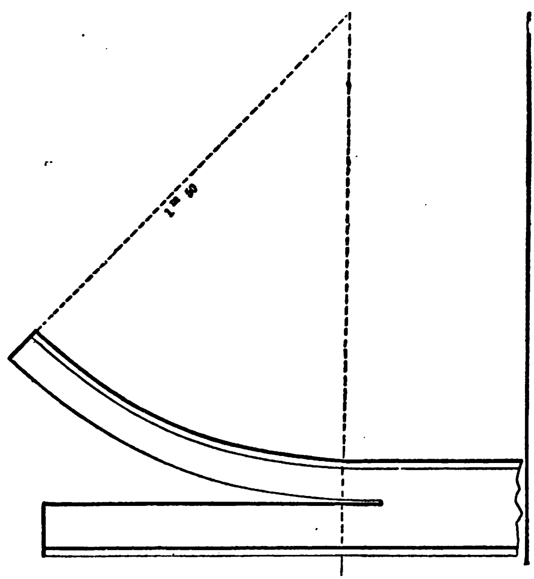


Fig. 68.

operation. For it will be understood that these parts were subjected during the whole operation, to an effort of flexure, and

they must have stretched more than those bearing this effort during a much shorter time. Besides, in the last period of curving, the parts near the beginning of the cut may have stretched much more within a short distance if the metal rested more at certain points than at others.

After these first trials, a new outline was adopted (fig. 68). The cut was continued 5.85 inches beyond the spring of the curve. This modification alone should, probably, have been sufficient to avoid the ruptures which had previously taken place; but, for more security, the slit which origianally was in the middle of the web, was lowered, so as to reduce to 4.29 inches the height of the portion to be bent. Under these conditions the heels could be turned without accident.*

The three beams worked up according to the original pattern and broken in the operation, were annealed, and the half of the web near the broken part which had suffered no deformation was curved to this same pattern again; two beams were brought to the required form, the third one breaking again. This experiment proves that annealing may notably improve the qualities of beams in the state in which they are furnished by manufacturers; they are, in fact, by the last pass in the rolls, subjected to molecular tensions of considerable importance, when the rolling is finished at a temperature below red.

The annealing of beams, in order to be perfect, demands very slow cooling, on account of the varying thickness of different parts of the section; nevertheless the metal in the thickest part is still thin enough to cool safely in the open air. I beams heated in a Siemens furnace and left on curving plates return to the surrounding temperature only after several hours, and no inequalites in hardness or resistance worth noticing, in their different parts, were ever observed.

* More than 150 beams of this pattern have been bent at the time of writing The elongation of the convex part was found to be about 6 per cent. and the 5.85 inches added to the cut showed a notable elongation.

However, the slowness of cooling is more important than with plates and angles of small thickness. For in fact, it was noticed that the two parts of a beam cut in a planer tore apart with a noise, when the thickness of the metal remaining to be removed was very small; and each portion of the web was bent to a curve, the convex side of which was toward the cut. The same phenomenon is observed in iron beams; it evidently results from the fact that the thin web, subjected to a more rapid cooling than the flanges, is compelled to stretch at the expense of its elasticity. When the flanges contract in their turn as they cool, this contraction cannot be complete on account of the elongation of the web; their fibres are subjected to tension that does not exceed their elastic limit. When the web is split longitudinally, this tension being no longer balanced, produces the observed curvature.

Beams heated in a gas furnace and left to cool in the open air, behave when they are split, in the same manner as those just out of the rolls without any subsequent heating; the internal tensions observed in splitting the webs of these beams are therefore not to be attributed to the action of the rolls. On the other hand it has been observed that beams when heated, split, and bent cold, are more easily subjected to this sort of work than those coming directly from the manufactory. The force applied to bring them to the required deformation is obviously less. It is then probable that simple heating restores to I beams a portion of the softness they lose in the last period of rolling. The metal after annealing is yet subject to a few internal tensions arising from the inequality of cooling, but these are weak and hardly worth noticing in practice.

Another series of I beams had to be curved and the angles of their flanges changed. These operations could be done cold, but they were mostly done hot. As cold treatment can furnish some explanations of the deformations soft steel can endure, we will describe the processes that were tried,

although some of them have defects which should prevent their use on a large scale.

In order to form a curve, the hydraulic press was fitted with the apparatus represented by figs. 69 and 69′—two dies fixed on the press exhibited, one convex the other concave, the curvature the greater part of the beams was to follow. Adding a few blocks allowed a slight change in these curvatures. The webs were held transversely by guides which prevented them from bending over laterally. In the first trials, it was ascertained that the beams as a whole reached the required curvature well enough, but the webs, on account of their small thickness, buckled under the effort of compression they had to bear. We then operated by transmitting the compression to the beam through a piece A (fig. 70), which, by embracing the

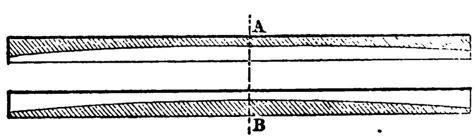
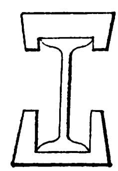


Fig. 69.



69′—Section A B.

web all around, prevented its buckling. The beam resting on two points on the lower die of the press, the upper end of the piece A was compressed by the upper die; after having ob-

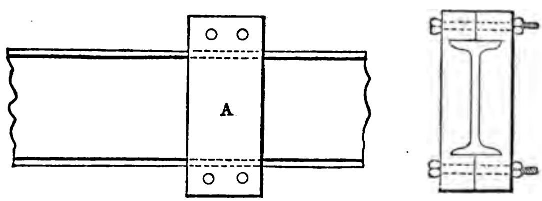


Fig. 70.

tained the required deformation, the piece was moved along

to subject another part to the same operation. By working on small lengths, and with caution, we were able to attain good results and regular curves. This process was applied only to pieces with right-angled flanges left unchanged. To remedy all defects, the operation should be followed by annealing. A few cases of rupture having occurred, this mode of working was abandoned, as soon as we were able to execute bending in the furnace.

Two processes were used to change the angles of the flanges:

The punching machine, as employed to do the same thing to angle-bars, was first tried, the die and punch were replaced by the pieces A, B (fig. 71). The punch A, in going down,

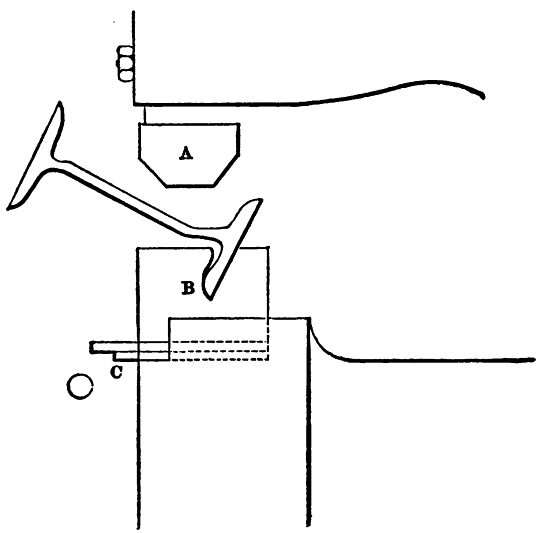


Fig. 71.

produced a flexure of the web around the point of its junction with the flanges; by operating a little at a time and taking care *to hold the flange* in the groove of the piece B, the beams

were thus shaped throughout their whole length. By varying the blocks, different angles were obtained at sucessive operations. One flange being shaped, the other was treated in the same manner. For more decided angles, the pieces A and B were replaced by others which were manipulated like the preceding ones.

This process required, in order to succeed, that the beam should be sustained at each end on blocking of suitable height, and also well held in the groove of the piece B; if these precautions were neglected, the effect of deformation bore on the flange that was being bent instead of acting exclusively on the web. As the modified punching machine was often engaged in this kind of work on angles, this method was little used for beams.

We also tried to change the angles of I beams in the hydraulic press with the apparatus fig. 72—two dies fixed in

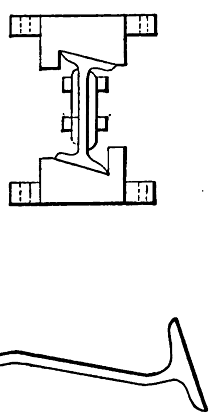
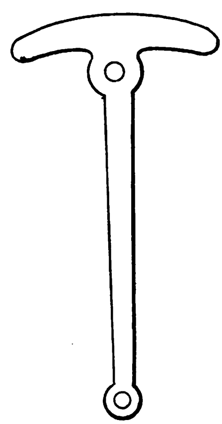


Fig. 72.



73.

each jaw of the press presented two inclined planes on which the beam flanges were to bear after the proper bending. Larteral sliding of the beam was prevented by flanges on the

machine ; and cast iron plates placed on each side and joined by a few bolts, opposed any flexure in the web. Blocks of different heights interposed between the flanges and the dies allowed a variation in the change of angle.

The I beams were thus brought more regularly to their form than by the first mentioned process, yet in both cases, the web exhibited a rather irregular section, exaggerated in fig. 72. The turning over of the flanges, instead of taking effect at their junction point with the web, pulled out of shape the portion of the web near the angle. It was necessary to heat and hammer the beam, to straighten the web ; in consequence of this, working hot altogether was preferred in most cases.

Curving hot was effected on curving plates, generally by the process used in bending angles and indicated above (fig. 55 and 56). The outline of the piece was defined by pins put in holes in the plate ; a sheet iron band bearing on the pins insured a continuity of contour. The I beam, heated in a Siemens furnace, was made to bear on the pins by blows of

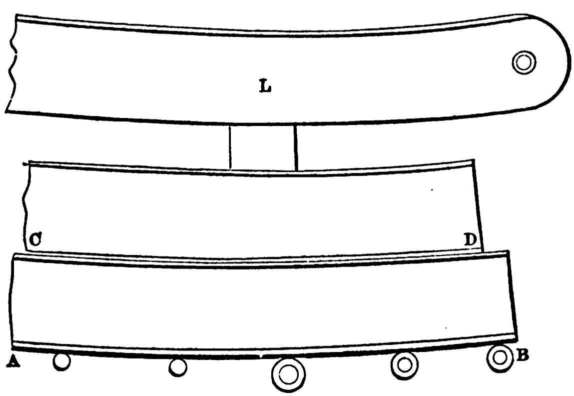


Fig. 74.

a wooden mallet, or by the use of anchor levers (fig.73) ; the *web was kept* from warping by hammering with a mallet. If

the operation was finished when the piece was red, even when iron hammers were used, annealing, from what we have seen before, could be dispensed with. But several heats were often necessary to arrive at the required curvature ; it was preferable to heat the piece several times rather than to expose it to cold hammering, which might have been dangerous. However, as sometimes it was impossible to dispense with a few hammer blows, it was made a rule that the beams were to be put back into the fire and get to a cherry-red heat, for a final annealing.

A great many beams were to be brought to the same curvature ; this was done by the apparatus represented by fig. 74, in which the beam was subjected on its two flanges to the pressure of a strong lever L, each flange being comprised between two pieces, A B and C D, having the required curvature.

Altering the angles of hot beams could have been performed in several heats by hammering each portion of the two wings, but it was preferred to accomplish it in two heats ; with this in view, the heated beam was brought between two straight pieces having the desired inclination (fig. 75) ; one of

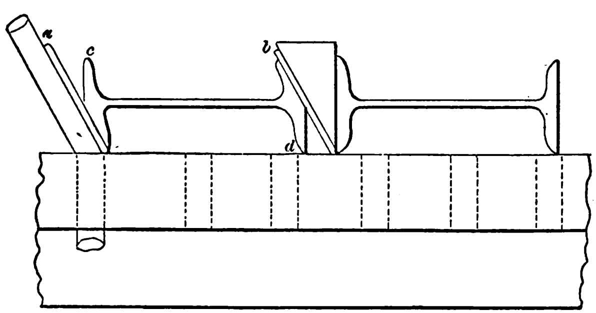


Fig. 75.

these was formed by a plate-band resting on the pins, the other consisted of an I beam furnished with wedges that could be varied. Another plate-band covered these wedges and formed a continuous surface of the required inclination. The beam be-

ing placed in the space *a b* the piece *b*, was tightly pressed by the lever, which brought it nearer the contour *a*; the flanges that were to form acute angles were compelled to bend.

The part *c* of the web, which was to form an obtuse angle, was brought by hammering to lie on the plate *a*. The beam was then reheated and put back in the machine, but turned over, so as to open the part *d*, of the second flange and bend it to an obtuse angle. In a third heat the beam was brought to a cherry-red and was left to cool, without any manipulation. The beams treated were first subjected to change of angle as if they had been straight. At the next heat, they were bent according to a determined pattern, by a plate-band resting on pins bent at an angle.

These manipulations while hot gave no difficulty or special phenomena, on accout of the precaution we took to anneal all the beams.*

We were able, by successive heats to bring these beams to very considerable curvatures—to fig. 76, for instance.

The considerable elongation which soft steel, well worked and homogeneous, can bear before breaking, renders it eminently fit to receive shocks or blows. To verify this fact, a few experiments were made with steel I beams, and others of iron, both of the same dimensions. The beams bore at each extremity on anvils about 2.62 ft. apart, and were laid flat, so as to rest on the edges of the two flanges; they were subjected to the blow of a 2970 lbs. ram falling from different heights. As the extremity of the ram was pretty sharp, a little wooden block resting on the beam bore the first effect of the blow.

The two *iron* beams tried under these conditions were broken, one under a fall of 32.8 ft., and the other under a fall of 16.4 ft.; they were in each case completely broken, and a few fragments were detached. By uniting the parts of same

* More than 400 I beams were brought to the required shape without any rupture.

beam, it was noticed that deformation before rupture must have been very small.

Two steel beams in their natural state, that is to say such as delivered by the manufacturer, when subjected to a 32.8 ft.

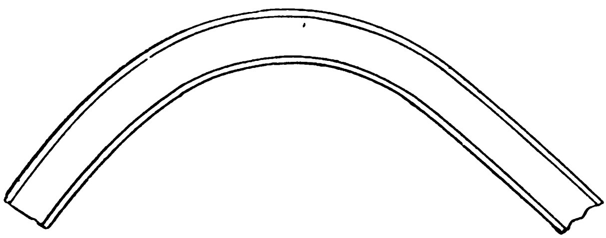


Fig. 76.

fall of the ram, showed no trace of cracking, the metal was flattened in a remarkable manner; fig. 77 represents one of them. In the section the bending over of the flanges in the most deformed parts can be seen. Another steel beam subjected to a 49.2 ft. fall was broken in two, but after having undergone a great deformation, no fragment was detached.

Farther experiments were made by placing the web in a vertical position; they gave results similar to the preceding ones, but a little less defined on account of the difficulty experienced in keeping the beams in position transversely.

These experiments showed the state of the metal after the different processes the beams had been subjected to.

We were frequently led to heat long beams on a part of their length only; the temperature being nearly even in the same transverse section, there should exist, after cooling, only slight pressure. Yet the thicknes not being constant, it became necessary to test the softness of the steel at the point separating the heated from the unheated part. With this aim in view, beams were raised to cherry-red on half of their length, and left to cool on the plates: they were then placed on two anvils 2.62 ft. apart so as to bring the web in horizontal posi-

tion. The 2970 lb. ram falling 32.8 ft. at the point of demarcation, produced the deformation fig. 77, without any cracks. This experiment made on two beams which gave the same flexure within ¾ inch, is very conclusive, and proves that

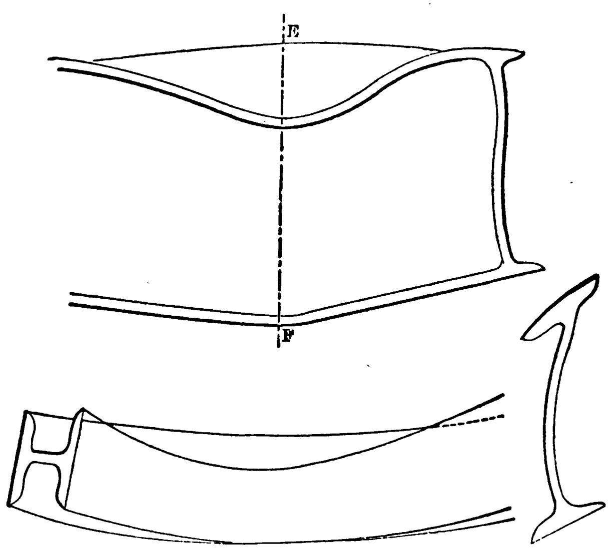


Fig. 77.

I beams can be heated in a furnace on part of their length without any damage.

We also investigated the influence a certain number of cherry-red heats might have on the fibrous texture of I beams. Two beams underwent 10 heats under these conditions ; when taken out of the furnace they were left to cool without any manipulation ; in trying them with the ram as in the preceding case, the deformation obtained was nearly identical with fig. 77′ ; no crack was observed. The beams used in practice *never* had such a great number of heats ; they did not ob-

viously by these repeated heats, lose any appreciable portion of their elasticity.

Other experiments by blows were recently made to test the effect of hammering and annealing on I beams. Four beams had their flanges turned over on a short radius, by the process just explained, using the hammer and the lever. The work

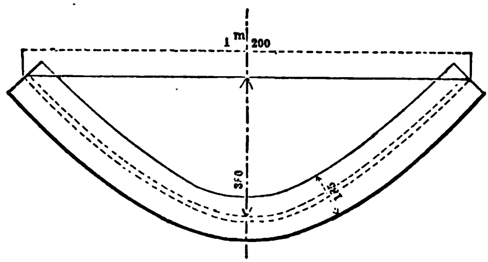


Fig. 77.

was the same for all ; but two of them were annealed ; the four were then subjected to the blow of the ram falling 49 ft. The two annealed beams were bent without breaking in a very remarkable manner, about as much as fig. 77, and much more than the beams in the natural state (fig. 77). The two unannealed beams were, on the contrary, broken into several pieces before undergoing any appreciable deformation, thus showing that the metal was very brittle.

This result is a complete commentary on the facts relating to hammering explained above.

These observations evidently prove the advantage of using soft steel to resist a shock or blow, when no difficulty in manufacturing or working up is to be encountered. On the other hand, it will be seen from the results obtained with beams heated several times or on a portion of their length, that in most cases, the work can be done with the same facility as with iron. Cannon practice on armor-plated targets, leading to the substitution of "cast metal" or soft steel plates,

angles and I beams, for those of wrought iron, fully justified the conclusions drawn from the preceding experiments. The metal was, in most cases, bent and twisted without breaking in any way except to allow the passage of the projectile. The fragments were not more than one-third as large as those given by iron under the same circumstances. In case of all the materials used in these targets, care was taken to subject them to a cherry-red heat, and let them cool in the open air on a homogeneous surface of cast iron plates.

Results of the same kind, relatively to blows, would have been obtained with very soft materials by tempering them instead of annealing them. For it has been seen that tempering, like annealing, causes the inequalities of treatment to disappear, and gives homogeneous products. But this result can be obtained only with very soft steels, capable, after tempering, of considerable elongation before breaking. This mode of proceeding would have the defect of complication in the stock of tools and fixtures ; moreover, it is probable that by tempering an I beam in parts successively, it would be impossible to retain homogeneity as is done by partial annealings. For these different reasons annealing the worked materials seems to us in any case far preferable to re-establishing their homogeneity by tempering.

CHAPTER VII.

ON RIVETING STEEL PLATES AND ROLLED BARS.

RIVETING, in steel construction, must be done according to rules somewhat differing from those adopted for iron. In order to join two or more pieces of steel, the rivets must be either stronger or more numerous than in case of iron, which has less strength.

The rivets may be made stronger either by making them of a stronger metal than iron, or by increasing their dimensions.

The first solution is the more attractive, and attempts have been made to substitute steel for iron in the manufacture of rivets. The conclusions arrived at in England seem to agree entirely with our own. The leading points in working steel rivets are, 1st, to heat them sufficiently, but not to go beyond a cherry red heat; 2d, to hammer and finish them as quickly as possible. Hammering, at a temperature below red, produces in the highest degree the defects of tempering the metal at the point of impact. The rivets thus consist of zones in different conditions, some capable of slight elongation and great resistance; others having less resistance and more stretching properties. In short, all the dangerous characteristics shown by a plate locally heated and hammered are to be found.

The rivet must be heated so as to be worked easily. If a cherry-red heat is overreached, contraction, resulting from

cooling, uses up too considerable a portion of its possible elongation, and the heads of the rivets are likely to break off.

It is also recommended to hammer and finish rivets very promptly, so that the carbon maintained in solution by the blows, may yet, while the rivet is red, by cooling without further working, be separated from the solution.

The English Lloyds formally protested against the use of steel rivets; in consideration of so categorical an exclusion, no experiments on the subject were made at L'Orient. Yet it is possibly that, if riveting had been done rapidly, by a regular pressure, like that of a hydraulic apparatus, more satisfactory results than hammer-riveting might have been obtained. The advantages which might result from the use of steel rivets did not seem important enough to encourage us in making any special experiments with them.

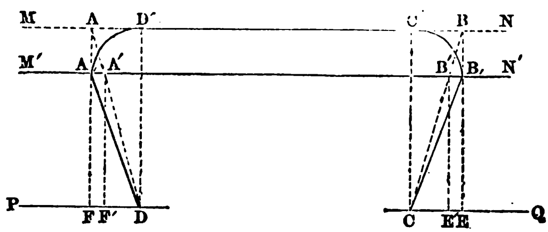
The increase in the strength of riveting for steel plates must be therefore found in increasing the diameter or the number of the rivets. Leaving aside the question of economy, the most satisfactory solution would probably be to multiply the number of the rivets, by putting, wherever possible, one more row than in iron constructions; but the increase in expense resulting from such a course would be considerable.

At L'Orient we prepared to add to the strength by enlarging the diameter.

It is estimated that on the average, steel plates with a thickness of ¾ can replace as to resistance to tension, iron plates with a thickness of 1. A 0.35″ inch steel plate is proved equal to an 0.46″ in. iron plate. The rules for riveting 0.46 in. iron plates were therefore applied to 0.35 in. steel plates; for other thicknesses a similar ratio was observed. This solution was simple, and presented no difficulty for flat or round headed rivets; but the question was a little more complicated for countersunk rivets. If we consider two plates joined by countersunk rivets (fig. 78), it will be seen that the *tearing away* of these plates can occur in two ways: 1st. By a

deformation of the plates, allowing the head of the rivet to pass through the deformed hole; 2d. By the compression of the metal of the head, which then can get through the undeformed hole. In reality, tearing away takes place through these two combined efforts, but they can be studied separately.

In the iron plate M N P Q having the same resistance as the steel plate M′ N′ P Q and receiving rivets of the same diameter, the first mode of rupture requires the compression of the region A D F surrounding the hole, or the shearing of a cylinder generated by the line A F; the second mode neces-



78.

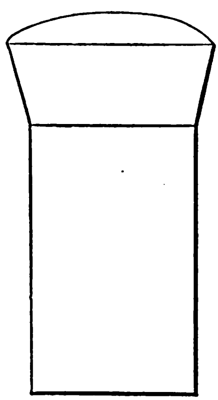
sitates the compression of the part A D D′ of the rivet, or the separation of a cylinder generated by D D′. If we now consider the steel plate M′ N′ P Q fixed with the same rivet, we shall see that the upper part of the rivet presents a sharp edge above the plate. Moreover, tearing away may happen by the rupture of the cylindrical surface generated by A′ F′, and slight compression of the part A A′ B B′ of the head. The surface of the cylinder of rupture is in relation to that of a cylinder generated by A F′, inferior to that of the thicknesses M P and M′ P. The tearing away should therefore take place sooner in the steel plate than in the iron plate. For this reason the contour D A D′ C′ B′ C was adopted for the heads of rivets; the steel plates therefore received more decided countersinking than the iron plates; the large diameter

A^1 B^1 being the same as A B, the proper diameter for the iron plate corresponding to resistance to tension.

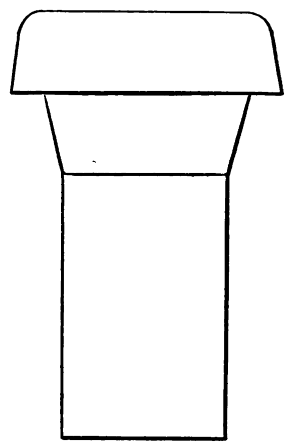
Under these conditions, the tearing apart of the plate must occur according to the cylinder A^1 FB^1 F the circumference of which is the same as that of the cylinder A F B E, and which by reason of the increased tenacity of the steel, resists separation like the latter. The rivet behaves as in the iron plate and the sharp edge A B is avoided.

All the countersunk steel rivets used in the works were made on these principles; fig. 79 represents an 0."85 inch rivet.

Flat headed rivets cannot be guaranteed to offer much



79.—Full size.



80.—Full size.

resistance; heads often break off after riveting, and the same fact is sometimes observed on carefully made joints submitted to a blow. These ruptures are caused, on the one hand-by the flattening which the head of the rivet is subjected to while being formed, and on the other, by the angle at the junction *of the head and the* body, which produces an effect compara-

ble to an incipient crack; then when the head of the rivet does not bear thoroughly on its whole surface, it is subjected to flexure, the leverage of which increases with the width of the head.

For these reasons, the flat-headed rivets used at L'Orient were shaped according to a mixed system recommended by Mr. Reed in his previously mentioned work. A part, in the form of a truncated cone (fig. 80), was interposed between the body and the head, and filled the countersink made for this purpose in the plate. This system allows much more confidence to be placed in the riveting. If one cause or another subsequently breaks off the head, the plates will not be abandoned to themselves, but will be kept in place by the countersinks. The height, and consequently the weight of the-flat headed rivet heads can be considerably reduced, and yet leave out of the plates an amount of metal large enough to allow for oxydization and wear in parts exposed to these influences.

The countersinking necessary to lodge the conical part of the heads was, in iron plates, punched out, without any subsequent work, by using dies a few millimeters larger than the punch. In steel plates this countersinking was obtained by drilling, while enlarging a punched cylindrical hole. So, in either case, the adoption of this form of rivets did not require an increase of work. Moreover, the manufacture of these rivets is not any more complicated than that of ordinary flat-headed ones; there is therefore no reasonable objection to the general adoption of this form of rivets.

It became interesting to know whether the heat of a rivet put very hot in its hole was capable of restoring to the surrounding region, warmed by its contact, a part of its original elasticity lost in punching. Strips of steel plates were punched on their axis; in each of these holes a rivet heated almost to white heat was set and headed. When they were cold, the strips were broken, but they gave exactly the same results as

punched strips of the same width without riveting. The heat transmitted by hot rivets to the walls of the holes they fill, is, then, quite insufficient to modify the existing conditions of the fibres of the metal.

CHAPTER VIII.

RECAPITULATION AND CONCLUSIONS.

THE facts related in the preceding chapters have all been explained on the theory we have adopted, and which in the actual state of our knowledge, seems to us very plausible. Our observations were generally made on two varieties only of soft steel, one from Terre-Noire and the other from Creusot. These materials behaved with such uniformity in the different uses and tests to which they were put, that it must be admitted that the greatest regularity has prevailed in their manufacture, as well as in the composition of the raw materials they were made of.

The plates and beams coming from these manufactories were generally most homogeneous, and we did not notice such flaws as the manufacturers of steel are so justly concerned about. We think such defects have been reduced in number and importance, but not, however, entirely suppressed. The considerable drawing out to which ingots are subjected after casting, probably conceals the smallest flaws they originally had, by reducing them to imperceptible threads of unimportant dimensions; it is hardly probable that the pressure of the rolls or the blow of the hammer welds the metal at the points surrounding the centre of the ingot. We have never observed, however, any defect attributable to the cause mentioned.

We have seen that the Martin steel from Creusot* behaved as some Bessemer steels might have done, if less carburized than those from Terre-Noire, and having, carbon excepted, the same composition. The presence of ingredients other than carbon evidently exert a great influence on the properties of the metal, and may modify the simple laws we have admitted; but it does not appear that their presence should cause any notable change in the explanations we have given.

The precautions to be taken in working up steel are easily summed up: 1st, Avoid any local pressure of whatever nature it may be; 2d, If local pressures have been produced by blows of a hammer, the action of the punch, etc. (which may, as we have seen, cause ruptures), heat the piece to a cherry-red in a very regular manner and as much as possible in its entirety—the whole of it at once, and let it cool in the open air on a homogeneous surface which has all over equal conducting power. This simple re-heating, which may be considered as annealing, for plates and bars, on account of their slight thickness, restores to the worked metal its original qualities, even if it was in a very unstable state of equilibrium.

The precautions our researches have proved necessary, agree in many points with those recommended by Mr Krupp, which in Mr. Reed's work, quoted above, are set forth as follows:

Mr. Krupp says as to this cold manufacturing of steel boiler plate:—"All projecting or re-entering angles must be avoided; the cut edges and rivet holes must, before riveting and bending, be rounded as well as possible, so that after shearing and punching no rough edges shall be left."

He recommends completely and uniformly annealing the plates at a dark-red heat after each principal operation, and

* The comparison we have made evidently holds only for certain varieties of Martin and Bessemer steel; it can, in no way, establish in a positive manner the superiority of one process of manufacture over the *other.*

above all, never to miss it at the termination of the various manipulations.

The advice he gives as to bending while hot is as follows: "The plates must be heated before bending to a temperature not above bright cherry-red. They must be heated on the largest possible surface and not on the edges only; it is best to heat the whole plate at once when it is possible. In this manner the strains resulting from heating and cooling, which are greater in steel than in iron, on account of its greater density, are uniformly distributed. The thickest and stongest plates may break if part of their surface only is heated, bent or cooled. The curvatures that cannot be obtained in two consecutive heats must be given gradually and uniformly to the whole plate. For instance, to bend a plate to a right angle, the whole plate must be brought to 30° first, then to 60°, then to 90°—that is to say, proceed by thirds. After the whole of these operations, the plate must be annealed at a dark-red; this annealing will equalize the strains resulting from the previous manipulations and will restore the molecular equilibrium."

Although we do not share completely all the views just quoted, we have thought it necessary to reproduce this passage in its entirety, as the precautions we recommend for "cast metal" do not much differ from the preceding ones, which apply to more highly carburized steel. It must be noticed that a dark-red heat is quite insufficient for the annealing of steel; it improves it, but does not restore it to its normal state.

We also believe we have demonstrated that a simple re-heating, with cooling in the open air, practically constitutes for plates and beams, as good an annealing as that performed in an air-tight chamber. This fact has great importance, as it considerably simplifies the difficulties that might be met in annealing steel.

These precautions, which are only an exaggeration of the precautions taken in the treatment of iron in boiler-making

cannot always be observed in an absolute manner; but it will be easy, in most cases, to carry them out without trouble or complication in the method, or in the products resulting from them. It will be prudent to choose certain grades of soft steel in preference to others, according to the nature of the work to be done. Thus, for all the parts of a construction which are rapidly manipulated and subjected to blows, it will be found advantageous to choose but slightly carburized steel, which bears partial heats and repeated hammering better, and is more easily welded; while for pieces relatively requiring less work or bearing continued working without blows, it will be preferable to use harder and stronger steel. At any rate, we do not think it would be very advantageous to adopt, in other than very exceptional constructions, less carburized steel than the variety furnished by the Creusot Works for L'Orient. By replacing iron with steel differing but little from it, the slight increase in resistance resulting from this substitution would be but a feeble advantage to compensate for the great difference in price. The soft steel, the resistance of which is 28.56 tons per inch, is easily manipulated; in the hands of experienced workmen, breaking is not to be feared; materials having to undergo several operations should be chosen from this class. The more carburized steels must be reserved for parts a little less manipulated.

Our observations were confined to pieces of small thickness; the difficulties encountered in working soft steel are greater as the thickness increases; mere heating and cooling in the open air can no longer be considered as annealing; the cooling must be effected in the furnace where the piece was heated, and its duration must be proportionate to the thickness of the metal. But very slow cooling allows crystallization of the internal parts, and changes the fibrous conditions obtained by forging. A tolerably satisfactory result may often be obtained by regular tempering; this operation, how *ever, may produce* too much alteration in the elasticity and

cause ruptures. After tempering, the central and surface fibres are often subjected to violent molecular tensions absorbing a large portion of their elongation. Moreover, the tempered metal is, from this very fact, in a much more unfavorable condition of elasticity than after annealing.

Masses of steel are always obtained by casting ingots; in this state, the steel does not possess the qualities subsequently given to it by drawing out under the hammer or in the rolls, as in most cast pièces, elasticity is very slight, and is acquired only by forging. In this state, sudden heating of the pieces should be avoided, since the expansion of the surface being first produced, may cause the separation of the internal layers. Forged pieces are less liable to break by the sudden heating of their surfaces, since the expansion of the metal at the exterior does not produce any pressure on the internal fibres; it only subjects them to a tension that their power of elongation acquired by forging allows them to bear. Nevertheless, it is judged more prudent to heat large pieces of steel gradually, by lowering the temperature of the furnace to dark-red when they are charged cold.

The same precautions are necessary when a piece has been subjected to a great number of heats and slow coolings, without any drawing out. It is known that, by this kind of annealing, the metal approaches the texture it had when just cast, and loses a great part of its elastic properties. This effect did not occur in the previously mentioned works, for the number of heats was always restricted. The slight thickness of the plates and beams used, also allowed placing them in a gas furnace without previously lowering the temperature.

It is important that the steels furnished by manufacturers should be brought to the most complete softness possible corresponding to their degree of carburization. For this purpose, rolling at a low temperature must be avoided—if not, it is necessary to re-heat the plates and bars before using them; this heating, if brought to cherry-red, takes the place of anneal

ing, and gives very good results. We do not think that a less temperature than this can be safely employed: precise experiments only could demonstrate whether it can be or not.

Judging from the experiences lately acquired at L'Orient, by the tolerably complicated constructions executed in soft steel, we may say substantially that all boiler work and plate work which can be executed in iron, and even constructions that iron plates and bars could not bear, can hereafter be undertaken in this metal without fear. But a rational method, similar to the one we adopted, must always be observed; it is the only way to avoid the annoyances steel has caused to constructors who have heretofore used it.

The bringing into common use, of a metal possessing great strength, while it is capable of enormous elongation, is a matter of the greatest interest. We shall esteem ourselves very fortunate, if by these few observations, we shall have contributed to this result, by allaying the doubts of builders and engineers who have occasion to employ steel in constructions.

THE END.

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